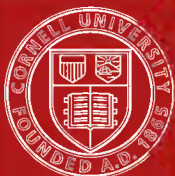


NOTES ON
CONCRETE
AND
WORKS IN CONCRETE

JOHN NEWMAN



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NOTES
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NOTES
ON
CONCRETE
AND
WORKS IN CONCRETE.

*ESPECIALLY WRITTEN
TO ASSIST THOSE ENGAGED UPON PUBLIC WORKS.*

BY
JOHN NEWMAN,
ASSOC. M. INST C.E.

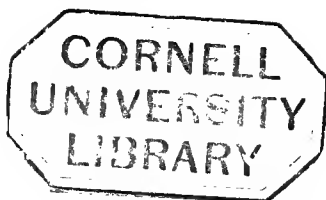


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1887.



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P R E F A C E.

EMBOLDENED by the success attending the publication of a Miller Prize (Institution of Civil Engineers) paper, on Iron Cylinder Bridge Piers, the author presents the following notes, the result of many years experience and some research, on CONCRETE AND WORKS IN CONCRETE, in the hope that they may be found useful for ready reference.

The author has especially written them to endeavour to assist those engaged upon works, and to supply the practical information required, and not to be obtained in so succinct a form ; and has avoided a dissertation upon the history or manufacture of true or adulterated Portland cements, which subjects are of greater interest to the professor or manufacturer than to the engineer. As concrete is extensively used in submerged, or partly submerged structures, the author has devoted five chapters to the consideration of some of the different systems of construction of such works.

In conclusion, he feels privileged in offering his acknowledgements to the authorities he has named and quoted.

J. N.

LONDON, *March* 1887.

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NOTES
ON
CONCRETE,
AND
WORKS IN CONCRETE.

INTRODUCTION.

PORTLAND CEMENT concrete has become one of the most important materials in construction, and can be used with absolute confidence that the work will be of great hardness and strength, and will not deteriorate, provided the necessary care is taken in the selection, storing, proportions, mixing, and deposition, which long and varied experience has proved to be indispensably requisite. By its judicious application many works can now be erected, more especially submerged, or partly submerged structures, that by reason of their great cost it was impossible to construct; for Portland cement concrete walls of average thickness for engineering purposes can be built for one-half or one-third of the expense of masonry or brickwork.

The importance of national harbours of refuge on the North-east coast, near the mouth of the Bristol

Channel, and west of Beachey Head, or in lieu thereof, a number of smaller refuge harbours, has been repeatedly urged for the last half-century; but the chief cause of their non-erection has been the great cost of construction; and, for a similar reason, some of the shelter harbour works imperatively required for the protection of the numerous fishing fleets on our coasts, have not been established. Doubtless, the cost of construction of a pier, or breakwater, in masonry or stone, could not be justified, except from motives of philanthropy; but, happily, by the employment of Portland cement concrete these works can now be made for one-half or one-third of their cost in masonry or stone, and in much less time; therefore, so far as regards the simple question of expense, distinct from that of utility, during the last few years, the circumstances have altered, and may possibly justify the erection of such piers and shelter harbours, which, if they had been in existence, would have saved many lives.

In the following notes no particular reference is made to the manufacture, composition, or scientific testing of Portland cement, its use on the work being principally considered.

Briefly, the valuableness of Portland cement is its power of firmly uniting other substances, its cohesiveness, durability, and adaptability to be moulded into any form with a rapidity of execution unattainable with brickwork or masonry.

Apart from the cement, the nature of the other ingredients is of great importance, the mode of mixing and depositing, &c., for the practical value of the

cement may be entirely destroyed without due attention to these details.

Although tests and experiments are generally made to ascertain the tensile and compressive strength of the cement, in work the strain upon the concrete, owing to unequal bearing and loading, irregular settlements, &c., is not necessarily directly tensile or compressive, but is frequently a shearing and transverse strain. Inasmuch as the compressive strength of cement is very much greater than its tensile strength, and apart from other reasons, the latter is the better general test; but its adhesive power to the aggregates should also be known, as that shows the true cementitious value of the cement, which is less than the tensile strength.

CHAPTER I.

FINENESS AND WEIGHT OF PORTLAND CEMENT.

Importance of fineness—The residue—Weight test—Sieves, &c.

THE importance of uniform fineness in Portland cement has been proved under every condition, and repeated experiments have shown that it cannot be ground too finely, or be too carefully sifted, its tensile strength being dependent upon its fineness when it is mixed with sand; and Mr. Mann's experiments also demonstrated that the finer the cement the greater the adhesive strength, it falling considerably as the amount of the residue increases; an analysis of the experiments showing that, approximately, the adhesive strength was not far from being inversely as the percentage of the residue upon the sieve.

One of the chief reasons which causes uniform fineness to be of such great moment is obvious, as the especial value of Portland cement is, apart from its own strength, its power of durable adhesion to other substances; therefore the object to be gained is to thoroughly and equally coat and cover any particles of gravel or sand, as perfectly as if they were surrounded by water, and the finer the cement is ground the nearer it approaches the desired condition of an impalpable powder. All coarse particles, i.e. small lumps

of cement in an unground, or partially ground state, should be removed, as they do not set together and are little better than powder ; although the identical lumps set readily, and as hard as desired when finely ground. If there were no other reasons for the necessity of very fine grinding this alone would suffice, and it is manifest that it is better to have more coarse sand in concrete, than particles of unground, or partially ground cement ; because the cement in such a state can only be regarded in practice as sand, although by nature, cement, and therefore, all residue upon a sieve after sifting increases the ratio of the aggregates, and reduces the effective proportion of the cement.

Mr. Grant, in some experiments with Portland cement weighing 113 lbs. per bushel, found that when unsifted it had a tensile strength of 375 lbs. per square inch, but when sifted, the same cement weighing only $110\frac{1}{2}$ lbs. per bushel, increased in strength, the highest test being 427 lbs. per square inch.

With regard to the important and controverted question of the weight of cement, and its influence on the strength of cement, it is possible to specify so heavy a weight as to demand coarse grinding, for the cement that is the more finely ground will be the lighter per given measure ; but it is to be observed that with similarly finely ground cements the heavier would in all probability be the better, because it would be obtained from the more thoroughly calcined material which, however, is the harder to grind. As a rule, the heaviest cement is the coarsest. Heavy cement has been ascertained to contain 30 per cent. of grains ex-

ceeding $\frac{1}{50}$ th of an inch in diameter, and such particles have been found by experiment, when mixed neat, to be incoherent and not to set.

A simple weight test may be said to be deceptive, as, in great measure, very heavy cements, namely, those heavier than about 113 or 114 lbs. per bushel, are not well or sufficiently ground. A weight test alone, without a specific degree of fineness, is, therefore, no indication of strength, but may be precisely the reverse. In all cases, the Portland cement is supposed to be well burnt, as that affects the strength; for instance, well burnt Portland cement, somewhat coarsely ground, experiments have shown to be stronger than soft clayey cement finely ground, both mixed neat.

In weighing cement care should be taken in filling the measure, because the weight can be increased as much as 10 per cent. by filling a measure from a considerable height, or with force; and the larger the size of the measure the greater the density. To ascertain the true weight of cement it should be gently run in from a hopper, the bottom of which, and the lower end of the shoot being at an elevation above the measure not exceeding one foot six inches, and six inches respectively, and the inclination of the shoot should not be steeper than is necessary for the cement to run leisurely: a slope of $1\frac{1}{2}$ to 1 to $1\frac{3}{4}$ to 1 usually effecting this. The weighing should take place immediately upon the material being received from the manufacturer.

It is well to adopt a standard measure and weight per bushel to ensure uniformity of cargoes and de-

liveries, and in comparing weights the measures must be of the same size.

In many experiments at Portsmouth Dockyard extension works, it was found that the average weight per bushel of the cement after screening was 106 lbs., against 115 lbs. before screening, and as delivered on the works.

The correct relation of weight to fineness and strength is of importance, because, if too heavy a cement is specified, in order to obtain the weight, it may be necessary to have coarse particles in the cement. These, in their unground state, although cement, for purposes of concrete must be regarded as sand, and somewhat dangerous sand, as they may "fly." It is, therefore, obvious that to specify too heavy a cement is to invite a manufacturer to deliver residue, and also to pay the price of cement for a material only equal to sand. A cement leaving a residue of, say 20 per centum after sifting, and which residue is used in the work, is not neat cement in strength, but four of cement to one of sand. In fact, to specify for an exceptionally heavy weight per measure, with the idea to gain strength, is to defeat the very object desired, and is to pay for useless weight. It is better and cheaper to pay more for a very finely ground cement than to buy coarse material at a reduced price.

In a few recent specifications no weight per bushel is specified, but the degree of fineness and quantity of residue is particularized, together with the time of setting tests and the breaking strain, &c. Thus a manufacturer can supply cement of any weight per

bushel subject to the condition that it has the required degree of fineness and strength, and does not yield more than the maximum residue allowed; the buyer being considered secure, as the finer the cement, provided its manufacture is identical, the lighter it is; and, therefore, the fineness required prevents an abnormally heavy cement being delivered, and an exceptionally light one is guarded against in the interests of the makers, if payment is made by weight. Perhaps, taking a general view, the better plan may be, as is sometimes done, to specify a fixed range within which scale the weight of the cement must be contained.

The heaviest weight is about 130 lbs. per struck imperial bushel, or $101\frac{3}{4}$ lbs. per cubic foot. To fix a correct limiting heaviness, or lightness, is a most difficult matter; but with the present knowledge of the material, and to exclude lightly burnt cement, although finely ground, there is no particular advantage in a cement weighing heavier than about 118 lbs., nor lighter than 108 lbs. per struck imperial bushel; and the most usual weights are from 110 to 114 lbs. per bushel; all weights taken before sifting. In Germany, where fine grinding prevails more than in England, Portland cement, weighing about 70 lbs. per cubic foot, or, say 90 lbs. per bushel, is not uncommon.

Respecting the number of meshes per square inch, and the amount of residue left upon the sieve after sifting, considerable diversity of opinion exists. The highest number is the German of 32,000 meshes per square inch, or 179 per lineal inch, the lowest having

about 1600 meshes per square inch, or 40 meshes per lineal inch, the maximum residue being the same in each case. In Germany, sifting is sometimes done by means of two or three sieves of different degrees of fineness, of course, commencing with the sieve having the least number of meshes per square inch.

In England, Portland cement ground as finely as in Germany is not freely offered. In England, 5800 meshes per square inch, or 76 meshes per lineal inch, is now frequently specified, and a maximum residue, after sifting, of 15 or 10 per centum by weight. 10 per cent. residue on a sieve having 2500 meshes per square inch is often named, but it is better to pay a higher price and obtain cement more finely ground, and a much finer sieve test is here recommended. As the fineness is increased, the weight per bushel will become lighter, and the specified weight must be correspondingly reduced.

It is obvious that exceedingly fine grinding increases the cost of the production of Portland cement; but it is undoubtedly better to increase the ratio of the aggregates to the cement, within reasonable limits, to balance the increase in cost, than have imperfectly ground Portland cement with a large residue after sifting, which residue is worthless in its unground state as a cementitious agent, although probably the better portion of the cement when finely ground, as it is generally the best calcined; hence it is obvious that rather than increase the number of meshes per square inch, and allow more residue, it is preferable to be satisfied with an average fine sieve, say, of 5800 to

10,000 meshes per square inch, and allow a very small residue, from 5 to 10 per centum as a maximum; thus ensuring that the hard or well-burned particles of the cement are finely ground, as they are not so easily ground as the softer particles, and, therefore, are the most likely to be the residue. Fine grinding of all the mass is the object to be desired, and not merely fine sifting with a large residue on the sieve. The majority of specifications err on the side of not requiring sufficiently finely ground cement, and allow too much residue.

It should not be overlooked, that if the size of the wire is not specified, the number of meshes per lineal inch does not show the size of the openings in a sieve. The size of the wire should therefore be named, as with the same number of meshes the area of the openings in the sieve can readily be doubled.

A usual size for sieves is for No. 60 mesh, or 3600 meshes per square inch; $\cdot 0086$ inch, or No. 32, B.W.G.; or $\cdot 012$ inch, or No. 30, B.W.G. For No. 120 mesh, 14,400 meshes per square inch; $\cdot 007$ inch, or No. 34, B.W.G.

The committee of the American Society of Civil Engineers' recommendation as to the fineness of Portland cement is—

First sieve,	2500 meshes per square inch.
Second sieve,	5476 " " "
Third sieve,	10,000 " " "

CHAPTER II.

AIR-SLAKING, STORING, AND SHIPPING.

Store sheds—Expansion on storing—Time required for aeration—
Effect of time, &c.

PORTLAND cement is generally believed to improve by being kept, if properly stored in a dry place and protected from dampness and draughts; but, as chemical changes take place during storing, it has been stated by Dr. Erdmenger that some Portland cements become slow setting, while others set more rapidly in consequence of being stored.

As a rule, it is advisable to store Portland cement in timber sheds, with a wooden or concrete floor, raised one foot or so above the level of the ground, unless a brick or stone building has been constructed for that purpose; for, if it be deposited to any considerable depth, it will probably crack and bulge, or rend a brick or stone structure, the increase in bulk of Portland cement after grinding being about 5 per cent., without an increase in weight. Almost all Portland cements increase in bulk after grinding and delivery from the manufacturers.

The aeration, or air-slaking, of Portland cement is of importance, as it is thereby purged of any lime in a free and uncombined state, which expands, and if

deposited in the work is a fruitful source to cause the concrete to "blow" or crack. It should, therefore, be spread in a shed for several days before being mixed. The depth of the cement in the store shed should be limited to about 4 ft. to 4ft. 6 in.; and it should be stored in bulk for not less than three weeks or a month before being used in the work. Time is essential to effect the air-slaking of the free lime in the cement, and no Portland cement should be employed until this has been done, which can generally be ascertained after twenty-one days have elapsed by the 5 per cent. or so increase in bulk. This expansion will either take place in the store shed, or in the work if the cement has not been air-slaked. It has been proved by experiment that after one year's storing in a dry place, or even in barrels, there is no deterioration in Portland cement, provided it is kept from moisture and draughts.

Attention cannot be too strictly given to the proper air-slaking of cement, although it has generally a tendency to make the process of setting slower. Even though the cost of temporary wooden sheds, and the inconvenience and delay from being unable to use the Portland cement immediately on delivery may be considerable, under no circumstances should it be abandoned, as the air-slaking of cement is not a mere fanciful refinement, but a practical necessity.

In shipping Portland cement to hot climates, it should not be put into casks until it is perfectly cool; and on its being taken ashore, it should be removed from the casks, be spread out, and turned over, in order

to get thoroughly cool before being used, or its strength will be depreciated. Mr. William Parkes has mentioned that the Portland cement used at the Kurrachee breakwater, which was shipped from England, swelled about 10 per cent., arising from absorption of moisture in transit, and in storage.

The effect of long voyages is a slight total increase of weight from the absorption of moisture; but when taken out of the casks cement usually swells, and becomes of about one-tenth less specific gravity than its weight when it has left the cement works. It is well to arrange with a manufacturer the weight of a cask and a sack, so as to make a standard; and in order to ensure uniformity in deliveries, and to facilitate shipping arrangements.

CHAPTER III.

TESTING PORTLAND CEMENT.

Cohesiveness and adhesiveness—Precautions in testing—Variable-ness of quality—General tests—Cement and sand test—“Flying” cement—Specifications, &c.

No normal test of the composition, strength, and durability of Portland cement has yet been decreed by English engineers, but some standard rules exist in Germany, and now also in France, Austria, Sweden, and Russia, and recommendations in the United States of America; but it should not be assumed because certain countries have adopted standard tests that nothing more is required to be ascertained respecting Portland cement, and that there is no occasion to attempt to improve its quality; neither should it be taken for granted because the Portland cement is good that necessarily the concrete made with it is the same. As the strength of cement concrete is greatly dependent upon the adhesion of the cement to the aggregates, it is important to know its cohesive power when mixed with sand, and its adhesiveness to the stones forming the gravel, and also to any material likely to be used in the concrete, or attached thereto. If cement possesses great cohesiveness, it does not follow that it has the same power of adhesion to any substance. This is

a point generally disregarded in these standard tests, which take into consideration the strength of the pure cement, and when mixed with three parts of sand; but omit a test of its adhesiveness to other substances, which constitutes its true cementitious value; for although the tensile test of cement when mixed with sand proves its adhesive power to that substance, it does not necessarily show its adhesion to the stone forming the gravel which may be of a different character to the sand. The sand test only partially meets the case, although it is of great value.

To effect a reliable test of Portland cement requires great care, as the strength of test briquettes is governed by many circumstances. Among others may be named the following; each of which should be considered. They are not named in their order of importance, as that would be most difficult to determine.

The age of the Portland cement after grinding.

Whether the cement has been properly air-slaked.

Whether a skilled operator, accustomed to testing and making the briquettes, is employed.

The amount of residue after the cement has been sifted.

Whether the briquette mould was filled at one operation, and all air-bubbles removed.

The method of filling the briquette mould.

Whether the briquettes are made by the same operator, the same day, under the same conditions.

The time occupied in gauging the cement and filling the briquette mould.

Whether the mould is shaken, or tapped, to make

the briquette more dense ; or filled and firmly pressed by a trowel, or by other means.

The amount of water used in mixing.

The quality and character of the water used in mixing.

The temperature of the water.

Whether the briquettes are kept damp by wet cloths, or in a damp atmosphere, or kept dry, or in water.

The temperature of the setting room.

The temperature of the testing room.

Whether the cement is hand or machine mixed.

Whether the materials are mixed when dry several times before being mixed in a damp or wet state.

The method of gauging the dry cement.

The season of the year the test is made, unless the testing room is kept at a uniform temperature.

The nature of the slab upon which the briquettes are made, whether it is impervious or porous.

The method of removal of the briquette from the mould.

The area of the breaking section of the briquette.

The form of the briquette, and the proportion of its periphery to the area of the breaking section.

The length of time elapsing between the setting and the testing of the briquette.

The position of the strain as regards the breaking section of the briquette.

The nature of the strain, whether it is suddenly or gradually applied.

The time occupied in applying the strain and in making the test.

The form of clip for holding the briquettes.

Whether the clip is hung upon pivots to prevent cross strain.

The equal, or unequal, bearing of the clips on the briquettes.

Whether the moulds are perfectly clean and dry, or wet, before the cement is deposited.

Whether the mould is of iron or brass, or wood.

From the preceding brief compilation of some of the matters which affect the testing of cement, although distinct from its composition, it may be readily imagined that a rich field for controversy is presented; and it may be doubted if any other material largely used in engineering structures requires in testing such constant observation and assiduous attention; hence the importance of knowing that any experiments have been properly conducted. Of course such laboratory tests will give higher values of strength than those made from material mixed in bulk on the work.

To show the variableness of the quality of Portland cement, a difference in strength sometimes occurs between each cargo, and even in the same shipment or delivery; consequently a regular system of testing should be instituted. It is now agreed that a simple test of the strength and character of neat cement is not necessarily a guarantee of similar powers when it is incorporated with sand, and therefore tests are specified when the cement is mixed with sand, usually in the proportion of one part by volume of Portland cement to three parts of sand, and the sand should be similar to that to be used in the work. Neat cement trials should

only be considered as showing the uniformity of the strength of different deliveries, and as a check on other tests, and not as an absolute indication of the value of the cement in work; but if the neat cement tensile tests are satisfactory, and the sand tests the reverse, it may be assumed that the sand is bad and not the cement. It is also advisable to test the cement in its unsifted state, as supplied by the manufacturer, in case the sifting on the works may not be properly done.

A mere test of neat cement after being seven days in mould cannot be trusted; twenty-eight days should be the least period to elapse from the filling of the mould to the final test, which, if it gives the specified strength and shows the desired character, can be taken as a reliable certificate of the quality of the Portland cement. Of course additional tests should be made between the time of setting and the final test, which latter must be satisfactory or the material should be rejected. Tests with neat cement should be made, in order to check the trials of cement and sand mixed, and the rate of gaining strength should be noted in all cases. If a Portland cement satisfactorily complies with the conditions of tests named there is scarcely the slightest fear that it will seriously deteriorate.

The tensile strength of neat Portland cement of good quality is at seven days old from 330 to 400 lbs. per square inch, and the increase of tensile strength between a seven and twenty-eight days' test is from 25 to 40 per cent. Briquettes one day in air, remainder in water. The tensile strength of 1 of Portland cement to 3 of sand test briquettes is about 140 lbs. per square inch

within twenty-four hours, and about 170 lbs. per square inch at twenty-eight days.

It should not be overlooked that it is possible to require too high a tensile strength, especially at an early date, and that the tensile strength, although important, is not all that should be desired in a good and sound Portland cement: for instance, over-limed Portland cements will give a high tensile strength at seven days, but be dangerous, especially in immersed work; as the excess of lime in the cement must, sooner or later, become slaked by moisture, and then the mass will expand, or crack, and the concrete probably be more or less disintegrated. A moderate tensile strength, say about 350 lbs. per square inch at seven days, and increasing with age, is to be preferred to a high tensile power attained within a few days of mixing and not afterwards increased.

With respect to the adhesive strength, which is the cementitious value of Portland cement; the most complete experiments yet made known are those of Mr. Mann, who has made upwards of 1200 separate tests.

The average cohesive strength of the neat Portland cement tested was after seven days, 425 lbs. per square inch. The average adhesive strength of the same neat Portland cement being 61 lbs. per square inch, and 84 lbs. per square inch, after seven and twenty-eight days' immersion respectively. The test pieces to which the Portland cement was attached were sawn, close-grained limestone.

The general averages of sifted fine cement through a silk sieve, 176 meshes per lineal inch, meshes $\cdot 004$ inch

square; were 78 lbs. per square inch at seven days and 93 lbs. per square inch at 28 days, for adhesion of mortar. The unsifted cement gave a general average of 57 lbs. and 78 lbs. per square inch at seven days and twenty-eight days respectively. The Portland cement was of good quality and possessed a high cohesive strength.

An analysis of these experiments shows that there is no general ratio between the adhesive and cohesive strength of Portland cement. In ten tests, 5 at 7 days, 5 at 28 days, the ratios ranged from 5 (cohesive) to 1 (adhesive), to 9 (cohesive) to 1 (adhesive) in the case of 7 days' tests: and 3 (cohesive) to 1 (adhesive), to 5 (cohesive) to 1 (adhesive) in 28 days; therefore, 7 days' tests are unreliable. The cohesive strength remained nearly stationary, but the adhesive strength increased very considerably.

Mr. Mann in the 'Minutes of Proceedings of the Institution of Civil Engineers,' vol. lxxi., part i., gives the following adhesive strength specification, which is the first one published drafted solely with regard to the adhesive strength of Portland cement.

"The Portland cement shall be ground so that not more than 45 per cent. shall be stopped by a No. 176 silk sieve, and its average adhesive strength after 28 days' immersion shall be as follows:—

"Cement passing No. 176 sieve, not less than 95 lbs. per square inch."

"Cement as supplied for use not less than 75 lbs. per square inch."

"Six tests being employed in each case."

The No. 176 silk sieve per lineal inch gives 30,976 meshes per square inch, the meshes being .004 inch square, which corresponds in width with a B.W.G. No. 36. Sawn, close-grained limestone can be the test piece for adhesive purposes. The cement as supplied for use means, mixed without sifting, and as delivered by the manufacturer.

Mr. Grant has given the adhesive strength of a mortar consisting of 1 of Portland cement to 2 of sand to ordinary bricks after 28 days, as from 15 to 30 lbs. per square inch.

All briquettes used for testing purposes should have an area of not less than 2 to $2\frac{1}{2}$ square inches, as smaller test pieces, although more convenient when many tests have to be made, are found to give too great strength per unit of area; but it has been pointed out that when the strength of the breaking area of each briquette of a different size is divided by its periphery, the strength per unit of area is nearly identical. The breaking area of cement test briquettes should be large rather than small, although sufficient cement can only be simultaneously gauged for one or two moulds instead of five or six.

The importance of testing the cement when mixed with sand cannot be over-estimated, because tests with neat cement, which is seldom used in work, do not prove that the cement is finely ground, but those with cement when mixed with sand in the proportions previously described, show if the cement is finely ground, or has particles which are not equally, or thoroughly, pulverized; and it has been shown by

reliable experiments that the coarse particles, or residue from the sieve, in their unground state, have little more than the strength of sand. The test of cement mixed with sand should never be omitted. In addition, coarsely ground cement when mixed neat gives a higher tensile strength than fine cement, but when mixed with sand the reverse is the case.

A ready test to ascertain if a cement will crack or "fly," is to make some pats or cakes of neat cement, and place them in air, and also in water, and make a daily examination of their behaviour, particularly at the edges. The pats should be about half an inch in thickness, but thinner at the edges. After 24 or 48 hours they should not show any sign of cracking at the edges, nor have a crumpled or swollen surface, nor should any part of the pat rise from the glass.

The standard Prussian test for "flying," of cement, briefly stated, is as follows:—A neat cement pat is mixed on glass, and after setting, the cake and glass are submerged. If the cake crumples, or cracks at the edge, after one or more days' immersion, the cement is considered a "flying" cement. Other tests by means of boiling and baking are sometimes applied.

Mr. H. Faija's test for deciding within 24 hours whether a cement will "blow," and if it is a safe cement to use, is to subject a small pat of it, immediately on gauging, to a moist heat of about 90° Fahr., and when set, which will probably be within two or three hours, to keep it in a warm bath at a temperature of about 100° Fahr., but not more. He found that good and properly aerated cement did not "blow"

at these temperatures, but an improperly made and very fresh cement will, sooner or later. The pat should be perfectly sound, and not swollen or blown in any way to be good cement. A test should also be made with a pat of cement when the latter has been air-slaked for two or three days.

As the compressive strength of Portland cement is very much greater than its tensile or adhesive strength (vide Tables, pp. 77-85), unless the concrete is to be used for an exceptional purpose, there is no occasion to ascertain its power of resistance to compression. If other tests are considered desirable besides those named, they should be in the nature of experiments as to the strength of the concrete or cement, as a beam or girder, although the shearing strength of cement is usually considerably greater than its tensile power.

With reference to specifications of Portland cement, almost every practical variety of test for fineness, weight, strength, and time of setting has been particularized. Doubtless, gradually a uniform specification, or one nearly so, will be established. At present the differences are most marked, and it is certain all cannot be correct, as they differ as much as 300 per cent. in their requirements as to fineness, 18 per cent. as to weight, and over 100 per cent. as to strength. There is uniformity only in the time of testing.

Under such circumstances the best course, bearing in mind the particular features of each case, is to intelligently follow and compare the specifications of the acknowledged authorities on the subject, which in all probability will be amended from time to time as fresh

light is shed on so complex a material. The entirely independent drafting of a correct Portland cement specification would demand much technical knowledge, intimate familiarity with the material in the test-room and on works, and life-long experiment.

CHAPTER IV.

TIME REQUIRED FOR SETTING.

Quick and slow setting Portland cements—Impure Portland cement
—Setting under hydrostatic pressure and in compressed air,
&c.

FOR engineering works it is generally desirable that cement or concrete should, within a short time of its deposition, nearly attain its greatest strength, which should be maintained; and with respect to the time required for setting, cement concrete in one situation may be required to harden quickly and have immediate strength, and it may be absolutely necessary to use quick setting material, even if the ultimate strength is thereby decreased. On the contrary, it may not matter that the cement should set quickly. The hardening of slow-setting cements is generally considered more trustworthy than that of quick setting cements; but seasoned cement will take longer to set than cement fresh from the manufactory. As a rule, it may be taken that quick setting cements are inferior in ultimate strength to slow, or moderately slow, setting. The reason is believed to be that while the mortar or concrete is setting, and during the first stages of induration, liberating lime, a mechanical action of settling is in progress amongst the particles, which ceases when the

concrete or mortar is set, leaving the chemical process to complete the induration, and the longer this mechanical action proceeds the denser the material becomes, and, therefore, the stronger.

With respect to the time in which a test cake of Portland cement should set, for engineering purposes, it is well if a thin cake sets within one hour, and if Portland cement, when made neat into a thin cake, allows the impression of a finger-nail after two hours if kept in air, it may be considered slow setting.

The time required for setting, or hardening, can be accelerated by using only sufficient water to enable the cake to be made, and by compressing the same. In warm dry air, cement will usually set quicker than in cool damp air, or when the air is saturated with moisture; it also sets considerably quicker in air than in water, and finely sifted cement also sets faster both in air and water than ordinary unsifted cement.

Mr. Mann's experiments upon the adhesive strength of Portland cement show that the quick setting cements, with but few exceptions, had more adhesive strength than the slow setting, whereas the slow setting had the greater cohesive strength.

The time required for the setting of neat Portland cement varies very greatly, being from a few minutes to some hours. Cement generally sets in from about thirty minutes to twelve hours, and more often from one hour to seven hours. Quick setting cements generally increase in temperature shortly after being mixed, sometimes as much as 10° Fahr., and then return to the normal temperature, but slow setting remain

practically the same. Because a cement shows high compressive or tensile strength at an early date after it is mixed, it should not be considered that it is undoubtedly good cement; and it is well to remember that its tensile strength has no uniform relation to its adhesive properties.

When cement cracks and blows on being placed in water, it sometimes results from an excess of chalk, one of the forms in which lime is found, producing what is called "free" lime in the cement; it may also be caused from an excess of clay. Cement that shows these symptoms should not be used in the permanent work. High tensile strength is generally obtained by an increase of chalk which, when in excess, will make the cement slower setting, but it will be liable to crack and "fly." Cement with an excess of clay sets very rapidly, but does not so completely indurate, is weaker, and attains to only a moderate degree of hardness, and loses to some extent the hydraulic properties of the excess of chalk cement. Grey chalk contains a percentage of clay, but white or upper chalk is nearly pure lime.

The proportions of chalk and clay adopted in the best manufacture of Portland cement vary slightly in each locality, according to the different geological conditions, so that no one analysis is an absolute guide. The better plan is to specify the tests a cement is required to stand, and leave the analysis of the ingredients to the manufacturer, unless it is some fundamental essential, such as that the cement shall not contain above 1 per cent. of magnesia and no carbonate of lime, as recommended by Mr. Harrison Hayter; as

he cannot but fail to have the greater knowledge of the process of manufacture of Portland cement, but a detailed analysis of its composition should be required with each delivery.

There is one point, however, which should be specified, namely, that no "foreign" ingredients be allowed to be mixed with the true Portland cement as generally composed and accepted, i. e. that no adulteration of the cement be permitted.

Extreme caution should be observed in receiving statements as to the good effects of adding any "foreign" substances to pure Portland cement. No newly composed cement should be used until its superiority is established by elaborate tests as to its adhesiveness, tensile, torsional, and compressive powers, and the absence of any tendency to "fly" or crack; and its durability must be proved, as the addition of a "foreign" ingredient may apparently increase one of its powers and decrease all or some of the others, and render the cement dangerous. In fact its behaviour may no longer be that of true Portland cement, and for all practical purposes it should be considered a new or different material.

What is called magnesian cement has been tried in France, but failed to succeed, as such cement swells in water or moisture, owing to the large quantity of magnesia in the rock from which it is manufactured. In the cement referred to, 16 to 28 per cent. of magnesia was present, being at the least some twenty to thirty-five times more than that in good English Portland cement.

Experiments during a period of six months, made in 1883 by German experts for the German Association of Cement Makers, showed that if "foreign" ingredients, such as silicates of lime, powdered blast-furnace slag, limestone, brick powder, lime, and fine sand, mixtures of slaked lime and sand, ground clay shale, plaster of Paris (if more than 2 per cent.), trass, and ultramarine were added, the strength of the Portland cement was impaired. On the other hand, Professor Tetmajer, of Zurich, states from his experiments that when Portland cement was mixed with sand, or finely ground ingredients containing silicic acid *in a state adapted for chemical combination*, adding certain ingredients, pure blast-furnace slag, composite slag, and mixtures specially rich in active silicic acid, the strength was increased and maintained.

It has been found that concrete will not set under hydrostatic pressure, and that the water pushes its way through the interstices of the stone before the cement has time to harden sufficiently to resist it. With respect to the setting of concrete in compressed air, the upper surface in contact with the air-pressure sets very quickly, so that the rest of the mass derives very little or no benefit from the air-pressure, unless means are taken to bring it in contact, or opposition to, the force of water. Small vertical pipes leading downwards to the bottom of the concrete, and placed within 1 foot of each other over the whole area of the concrete, have been used to obviate this difficulty. It is advisable in all cases to test the setting powers of any concrete to be used under a similar pressure to that which it will

have to sustain when being deposited. General experience seems to show that concrete laid down under compressed air sets quicker and slightly increases in strength provided it is deposited in thin layers, which allow any excess of water to escape.

Professor Hayter Lewis's microscopic experiments with a power of 110 diameters on good and bad Portland cement, showed that the particles in good Portland cement were angular fragments, like small scales or thin splinters, and those of bad cement resembled small nodules, or rounded grains like sand, and this was found to be the unvarying rule after large numbers of specimens had been tested.

CHAPTER V.

SAND, GRAVEL, AND STONE.

Proportions, character, coarseness, form, and size—Gravel, stone and sand, making good and bad concrete and mortar, &c.

THERE are two proportions of the gravel and sand used in concrete, which should be ascertained before deciding upon the ratios of the mixture. They are:—

1. The quantity of sand required to fill the interstices between the stones in the gravel or shingle.
2. The contents of the interstices in the sand, which, however, are slightly less than the amount of cement required to fill them completely.

Under the heads of “Proportions of the Ingredients” and “Mixing Concrete” is described a method of ascertaining the proportions of cement and sand required to mix with the stone or shingle.

If the natural shingle or gravel varies in character, every effort should be made to blend it and cause it to be uniform, in order to obtain equal strength.

A simple way to find the proper proportions of gravel or shingle to sand is to screen the gravel or shingle and proceed to use the water-measure test previously referred to, to ascertain the relative cubical contents of the stone, and the sand required to fill its interstices;

and here it should be named that the water must be gauged as it is poured into the measure, and not after that operation.

It is well if the amount of sand in the gravel or shingle in its natural state as excavated and delivered on the works is ascertained. To do this a certain volume or measure of gravel or shingle, preferably in a damp state, should be first thoroughly screened and the residue carefully kept, and then the screened gravel or shingle should be washed and the residue added to the other sand; on this having been done, the whole of the sand should be put into a measure; the water required to fill up the measure and gauged on delivery into the vessel will show by deduction from the total cubical contents of the measure the volume of sand in the measure; and a similar operation must be performed with the gravel or shingle, when the proportions of sand to gravel or shingle will be made known.

It is only necessary to remember the almost universal presence of sand in the earth to declare its variety, from the quartzite rock, millstone grit, red sandstone, &c., to that of mere "blown" sand, such as is contained in the low sweeping hills by the seaside, or in the restless desert.

Sand varies in character very greatly, and is of different colours; it is found pure, and also mixed with every possible impurity, being any mass of fine particles of silicious rock, pure or impure, and consisting of minute concretions or fossils indissoluble by water.

Moderately hard sandstones, being those more often met with, contain a large or small admixture of clayey

or calcareous matter; and greensands have green particles of silicate of iron in them.

Sand, upon which much friction from wind and water has taken place, seldom has any coating of metallic oxides upon it, and is more grey in colour. As a rule, the more vegetation found on sand rocks the more impure and argillaceous is the sand; and the loose movable sands of white grains and considerable fineness, bare of vegetation, are characteristic of sand in its unmixed state.

It is customary to specify a certain porportion of sand and gravel to Portland cement without any reference to their character, except that the sand must be clean and sharp, and free from loamy particles, and pass through a sieve of about 400, and be retained upon a sieve of about 900 meshes per square inch; and the gravel be clean and no stone to exceed a certain size; such as the stone to pass through a two-inch ring, although sometimes Thames ballast, &c. is named, and river sand.

Considering the very varied character of sand and gravel, it seems that more attention should be given to the particularization of the sand and gravel, remembering the locality of the works in each case, and the geological features of the district from which, for reasons of economy, the sand or gravel must be obtained. The value of it from an engineering point of view may be very different, even in a small area; and to be most particular as to the character and quality of Portland cement, and apparently regardless of that of the sand and gravel, although the latter form about 85 to 93 per

cent. of the volume of the concrete at the time of mixing, is hardly capable of vindication, especially as Portland cement concrete should be a monolithic mass, and the effect of sand is to retard the process of induration and to decrease the strength. Similarly with regard to gravel, for it can be obtained from almost every kind of rock, whether simple weatherings or boulders, worn, broken up, and rolled by mechanical attrition.

German specifications require the sand to be prepared by sifting washed sand through sieves of 387 meshes per square inch, to expel the coarse grains; and all fine particles are removed which pass through a sieve of 774 meshes per square inch.

The Austrian standard sand tests are as follows:—The sand must be clean washed crushed quartz, sifted through a sieve of 413 meshes per square inch, wire $\cdot 0086$ inch in thickness, No. 32, B.W.G., then through a sieve of 929 meshes per square inch, wire $\cdot 0071$ inch in thickness, No. 34, B.W.G. The residue on the latter sieve is the standard sand.

The recommendations of the Committee of the American Society of Civil Engineers, as to sand, are that:—The first sieve should have 400 meshes per square inch, the second 900 meshes per square inch. The sand to pass the 400 meshes sieve, and be caught on the 900 meshes sieve. The sand to be crushed quartz, as the committee found none other sand equal to it in sharpness, and uniform hardness of the particles. The sizes of the sieves are those that have been adopted previously by Mr. J. Grant, Metropolitan Board of Works, London, and others.

The sand should be as coarse as possible consistent with making fine mortar, and if it should be retained on a sieve having somewhat fewer meshes than that specified, it should, within reasonable limits, not be necessarily rejected.

The character, degree of fineness, and the form of the sand grains affect the strength of the concrete. The sand should be free from all loamy, or argillaceous matter, and that obtained from the hardest sandstone rocks should be preferred, which has its grains in a pure state, i.e. not coated with material that may be called a foreign substance.

The shingle, gravel, or sand cannot be too clean and free from impurities, especially in thin work, and when combined with brickwork or masonry; but in large masses it may not be so important, although every effort should be made to cleanse it.

Very fine, or fine sand, even if perfectly clean, should not be used for Portland cement concretes, or mortars, as by repeated experiments, and for the several reasons herein named, it has been proved to lessen their strength very considerably, even as much as 40 per cent. as compared with coarse sand. An explanation of which decrease in strength is, that fine sand in a given bulk has necessarily a much greater number of grains than coarse sand, and as there are more grains to cover with cement the difficulty of thorough incorporation is increased, and further it has been shown by Professor Lewis that, under the microscope, each grain of sand is surrounded by a small film of cement, and that vacuities exist between the particles of sand and

the cement; it is, therefore, obvious, the fewer the grains the fewer the vacuities, and the more solid the mass.

Similarly, when a certain proportion of sand is used with the gravel in concrete, which should generally be the case, as if the interstices between the ballast or gravel are not filled with sand, the concrete or mixture will be much stronger and more porous than desired; the sand should not be fine, and additionally so, as pure sand has no coherence, and, therefore, unless each grain of sand is covered with a film of cement it will merely rest against the surface of the stone of the gravel, to which it has no adhesion.

If sand is not used, although there is always a little sand with shingle or gravel, the concrete is rough, has vacuities in it, and is consequently porous, and appears honeycombed, especially on the face, and the holes, as nearly as can be judged by the unaided eye, with concrete in the ordinary proportions, occupy from 5 to 12 per cent., of the cubic capacity, depending upon the size, form, and character of the gravel.

Fine sand will have more interstices than coarse sand, usually from 10 to 20 per cent.; although it varies considerably, and ordinary gravel will take about one-third of sand to fill its interstices.

The practical result of a certain proportion of gravel and sand being used to a fixed quantity of Portland cement, is, if the interstices are filled, that the stones of the gravel become imbedded in a matrix formed of the proportions of sand and cement specified.

With regard to the form of the particles of sand, the

angular, small scale, or thin splinter form of the grains is better than the spherical, nodular, or rounded shape. In soft and quickly perishable sandstone, the grains are chiefly spherical, whereas in durable, compact, and strong sandstone they are sharp and angular. In the former there is considerably more foreign substance attached to the grains than in the latter, therefore, the latter are much purer than the former, and better for engineering purposes; and the sharp grains will appear clean, clear, and translucent, and not dull, murky, and opaque, as the rounded grains frequently do.

Pure sand has no coherence, neither is there any bond, overlapping, or wedging in rounded grains of sand; but in the angular, sharp, or pointed form there is a tendency to compactness, and friction is obviously greater.

Rounded grains of sand have generally been fashioned by mechanical attrition caused by weathering and water, and are more polished than the sharp grains, and, therefore, do not afford so good and rough a surface for the cement to adhere to; nor is the ratio of their surface area to their cubical contents as large as in the pointed, angular, and fragmentary form, a not unimportant point as the strength of concrete is dependent upon the thorough incorporation of the particles. Within reasonable limits, the superficial area of a grain of sand, or a piece of stone, should be as large as possible as compared with its cubical contents, in order that the cement may have a considerable surface to which to adhere, therefore, neither should be nodular or round.

The grains should be of uniform size, in order that equal strength and settlement may be obtained; the great stability of masses of material, angular in form, and uniform in size, is daily seen in breakwaters and roads.

The sand and stone should be as hard as possible, as cement has a greater adherence to a hard than to a soft surface, and that obtained from the most durable rock should always be preferred, for if the stone on the face becomes disintegrated, the concrete will gradually decay, although the best cement may have been used.

Coarse clean sand, such as is found on a sea-beach, makes good mortar; and coarse sand, as previously named, makes a stronger mortar than fine sand; but if sufficient coarse sand cannot be obtained, the coarse and the fine sand should be thoroughly mixed and mingled, as stronger mortar is so made than with fine sand alone. Briefly stated, sand from the hardest rock is much better than from soft sandstone, and the largest, roughest, coarsest, and most fragmentary grained sands are the best for making concrete, or mortar; also large irregular shingle makes stronger concrete than smaller, more worn and attrited.

It will generally be found that the size of the shingle and sand varies considerably along a coast, depending upon the facilities for attrition, but it frequently happens that the most exposed places have the largest, hardest, cleanest, and coarsest sand and shingle. During setting, cement concrete with angular particles of sand, or gravel, resists any tendency to slide in the work when temporarily and irregularly deposited, and

any erosion of the cement between the particles, better than concrete made with rounded grains of sand and gravel, the latter, such as Thames ballast; and the friction between the surface of the gravel and sand and the cement being greater, separation of the cement from the aggregates is not so readily effected during deposition. It also forms a more rugged surface for the attachment of layers, and the concrete settles more readily when rammed.

In breaking up Portland cement concrete it is found that with sand and gravel of angular shape, the mass is firmly joined together, and that there is but little appearance of a tendency to separate, but the reverse is the case with rounded stones. With the latter in the gravel, more sand, as a rule, is required than with angular stones, and, therefore, it is not so strong, and there is no wedging of the particles which conduces to strength.

The strength of concrete being dependent upon the adhesiveness of the cement to the sand and gravel, if the cement be very good, and the sand and gravel indifferent, the resulting concrete cannot be good.

In using large stones bedded in cement, great care should be taken that the stones do not touch, but are surrounded with cement.

When no material for mixing with the cement can be obtained, clean rock can be crushed by stone-breaking machinery at a small cost, and it will make an excellent blending ingredient, if the rock is hard, and one usually better than natural sand; but all powder should be removed from the stone or sand when

crushed, as experiments have proved that it reduces the strength of the concrete, and it is well to wash the stone and sand after it is broken.

In countries such as India, where very little sand is found of sufficient sharpness, brickdust is often used, and is preferred to fine sand. The particles of the brickdust should be as hard as possible.

Mr. W. Maclay (*vide* the 'Transactions of the American Society of Civil Engineers,' vol. vi. p. 311) made a great many experiments to ascertain the relative tensile strength of Portland cement mixed with very fine white sand, and sharp clean building sand containing a large proportion of coarse particles. Fine sand diminished the strength as against coarse sand, with 1 of sand to 1 of Portland cement, 11 per cent.; and the reduction is greater if more sand is used.

The gravel, or ballast, which in a given cubical measure requires the smaller quantity of sand to fill its interstices, is to be preferred, provided the angularity and roughness of the particles are equal, inasmuch as less sand is required, and no increased quantity of cement, and, therefore, the stones are bedded in a stronger mortar having greater adhesive and other powers. For example: Assume a concrete to be 6 of gravel, having no sand attached to it, 2 of sand to 1 of Portland cement, which is 6 of stone set in a 2 to 1 cement mortar; but, if the 6 parts of stone require 3 of sand to fill the interstices, it is 6 of stone set in a 3 to 1 cement mortar.

Eight of stone and $2\frac{2}{3}$ of sand to 1 of Portland cement is to be preferred to a mixture composed of 6

of stone and 3 of sand to 1 of Portland cement. It is assumed that the sand fills the interstices in the stone, and that thin face concrete is not under discussion. Reference to the tables, pp. 77-85, will show the difference of the approximate strength of concrete composed as described.

It is no indication of the strength of a concrete to state 6 of gravel and sand to 1 of Portland cement, or 8 to 1, or 10 to 1, unless the quantity of sand required in each case to fill the interstices is named, and equally proportioned. Assuming a 6 to 1 concrete required 3 of sand, and a 10 to 1 also 3 of sand, the relative strength of the concretes would not be inversely as about 6 to 10, but would nearly approach, for in each case the stone would be embedded in an identically composed mortar, although there would not be such a thorough incorporation in the 10 to 1 as in the 6 to 1 mixture. Hence the importance of having only enough sand to fill the interstices.

Mr. Kinipple, at Garvel docks, experimented upon the strength of Portland cement mortar mixed in the following proportions:—1 part of Portland cement to 1 part of sandstone, crushed in a Blake's crusher, and also mortar made of 1 part of Portland cement to 1 part of pit sand. The mortar mixed with the crushed sandstone was uniformly 55 per cent. stronger than that made with pit sand. The tests extended from seven days to three months. The average breaking weight on a $2\frac{1}{4}$ square inches area was 592 lbs. for the crushed sandstone, and 381 lbs. for the pit sand, or respectively 263 lbs. and 170 lbs. per square inch.

It is advisable, if the concrete will be placed in sea-water, that the shingle or aggregates should be obtained from the locality in which the works are situated, as they have already been subject to the chemical action of the salt water, and will therefore be less affected by it.

If very porous material is used instead of gravel or stone, it absorbs a considerable quantity of cement, in addition to being friable, and liable to disintegration; and it requires to be soaked with Portland cement before it is fit to be used as an aggregate, therefore, it should not be employed if any other harder and stronger material is available, although it has shown, and may show, after thorough impregnation with cement, a higher compressive strength than non-absorbent substances. The cost of the absorption of the cement will very probably equal that of obtaining a hard and strong aggregate, and the latter should always be preferred.

All absorbent material used in making concrete should be saturated with water before the cement is applied, in order that the cement may not be deprived of the moisture necessary for setting.

Mr. W. Smith has mentioned that at Aberdeen graving dock, built upon pervious soil, where the concrete was subjected to hydraulic pressure every time the dock was emptied, the concrete facework was made of 4 parts of crushed granite to 1 of Portland cement. It was very hard when kept dry, but when soaked with salt water the Portland cement gradually uniting with the felspar in the granite, separated the

chalk and clay in the cement, and formed a white mud. By washing the surface of the concrete with a strong solution of carbonate of soda, the necessary adhesion was obtained with the face concrete.

In perfect concrete the cementing agent should be of the same strength as the aggregate, under all strains in any direction, and subject to like conditions; and to obtain this it is necessary that the attaching area of the particles forming the gravel and sand, enables the cement mortar they are embedded in to adhere to the stones with equal strength to that it possesses in bulk, and that the stones are regularly spaced, and of the same quantity, relative position, and cubical measurement in the whole mass. Such a condition is an impossibility in work, nevertheless, by taking into consideration the points named, if there is a choice of gravels or stones, the better can be selected.

Some aggregates that do not make good concrete or mortar.

Loamy or argillaceous sand.

Very fine sand, such as "blown" sand.

Fine sand.

Road or ditch sand.

Impure sand or stone, i. e. that is covered with a scale or humus.

Sand or stone impregnated with sewage, or ammoniacal water.

◆ Round or nodular grained stone or sand.

Stone or sand from soft sandstone rock.

Sand which is dull, murky, and opaque.

Stone or sand with a surface very smooth and polished.

Stone or sand that has lime scale attached to it.

Pit sand, as a rule.

Soft stone, or sand with soft grains.

Some aggregates that make good concrete or mortar.

Stone or sand from quartz rock. Granite chips.

Stone or sand from hard sandstone or other hard rock.

Split sea beach-stones if they have not very smooth surfaces.

All very hard angular and rough-faced stone or sand.

Sea beach shingle and sand, if not nodular and polished from mechanical attrition.

Sand from a river whose bed and watershed are rocky.

Note.—Preferably it should be taken along the course of the river, and not at its mouth.

Sand with large grains.

Note.—In the case of sand, whose grains are equally coarse or rough, use the larger grained sand.

Sand with coarse or rough grains.

Note.—In the case of sand with grains of equal size, choose the coarser or rougher.

Sand which is clean, clear, and translucent.

The hardest stone or sand should be used.

The stone or sand should be angular and fragmentary in form.

The surface of the stone or sand should be rugged and coarse.

Stone broken from pieces of hard rock by a machine, the powder being removed.

Sand obtained from hard rock crushed by machinery, the dust being removed.

Sand or stone obtained from rock which is the most durable.

CHAPTER VI.

PROPORTIONS OF THE INGREDIENTS.

Quantity of cement and stone—Proportion of sand most important—Residue not to be considered Portland cement—General composition and the proportions of concrete.

WATERTIGHT concrete cannot be produced unless the cement, which is supposed to set perfectly watertight, entirely fills the interstices of the aggregates, and it is, therefore, important to determine the minimum volume of cement requisite to fill them, and also to remember that sand retards the process of induration of the cement, and weakens the mass. If a volume of cement be used slightly in excess of that of the interstices of the aggregate, there will be, provided the materials are properly incorporated, sufficient cement to completely encircle and cover each particle of the aggregates, but no more sand should be used than will occupy the interstices in the gravel.

A simple method of ascertaining the quantity of cement required in concrete is as follows:—With the gravel, or stone, fill completely by shaking and ramming down a watertight box or measure, the cubical contents of which are known. Then add as much damp sand as possible, shaking it down amongst the gravel, the quantity of gravel, or stone, and sand being gauged before they are deposited. Then pour in as much

water as the measure will contain; the quantity of water gives the net cubical contents of the cement required to coat the particles, which, however, should be increased by about 10 per cent. to allow for imperfect amalgamation, which cannot be so complete as with water, and to ensure that all the interstices between the sand are filled with cement.

In a similar manner the volume of the interstices of the shingle or stone can be ascertained. Tightly fill a measure with the stone and pour as much water into it as it will hold; the volume of water required is the cubical contents of the interstices which should be filled with sand.

In relation to strength, it has been proved that the strongest concretes are the cheapest, and the tensile strength of concrete made of Portland cement is, approximately, nearly in proportion to the quantity of cement in it, the aggregates being of a similar nature.

In stating the proportions of the different ingredients in concrete, the correct way of naming them is to compare the cubical contents of the cement with those of the other materials. Any sand that may be used, if in such quantity as only to fill the interstices of the gravel, cannot be taken as adding to the quantity of the aggregates. Assuming a mixture to be 6 of gravel, 2 of sand, and 1 of cement, the proportion of the aggregates or other ingredients to the cement is 6 to 1, and not $6 + 2 = 8$ to 1. The concrete is 6 of gravel set in a mortar of 2 of sand to 1 of Portland cement.

The sand should fill the interstices in the shingle or stone, and should always be regulated with care, as the

strength of concrete greatly depends upon the proportion of the sand and cement mixture in which the stone or shingle is set or embedded; hence the ratio of sand to stone or shingle is of great importance.

Respecting the proportions to be used between the cement and the other ingredients, no rules can be made. The situation and purpose of the work, the degree of cleanness, sharpness, durability, and angularity of the sand and gravel, or ballast, and the other questions previously and hereafter mentioned, must be considered.

The system of facing concrete can be adopted in many cases with advantage and economy, see pp. 86-89, inasmuch as a comparatively weak concrete can be frequently used, provided it is hermetically coated with a face of impervious concrete. It is probable that future practice will incline in the direction of forming the hearting and all unexposed masses of concrete of a large proportion of angular stone of small size, such as will pass through a ring of about three inches in diameter in any direction, say 9 to 12 of stone to 1 of cement, without any mixture of sand, except that which adheres naturally to the stone; the rock or stone concrete necessarily being of a porous character, although possessing great strength, as the stones are encircled by neat cement and not cement and sand; hence the necessity of preventing the percolation of water into the mass by having a thick facing of impervious material. A computation, however, should be made of the cost of increasing the richness of the mass and having no face concrete. In thin work a facing may not be economical, but in such structures as break-

waters, dock walls, &c., it is most valuable. If no impervious face-concrete is adopted, sand should be used sufficient to fill the interstices in the gravel or stone, and the cement should fill those in the sand.

About the weakest cement mortar that the gravel or stones are embedded in is 4 of sand to 1 of Portland cement; but this is a feeble mixture, and 2 parts of sand to 1 of Portland cement should not be much exceeded for exposed and heavily strained work, and it may be found that with a proportion of sand to cement greater than 2 to 1 the mortar may lose more in strength than the cost of the additional cement to make it a 1 of Portland cement to 2 of sand mixture.

If Portland cement concrete is to be used for facing copings and steps it should have no sand mixed with the granite, quartz, or rock chippings, which make the best aggregate for this purpose, in order to render its surface moderately rough. Small pebbles should be used for concrete paving and no sand; on the other hand, for watertanks, reservoirs, aqueducts, pipes and sewers, the concrete must be impervious to water, and if the concrete is not faced, preferably no stone or gravel should be used, but the mixture should be cement and sand, and although fine sand makes bad mortar it lessens the porosity of the mixture. If gravel is used for these particular works, the cubical contents of the cement and the sand should be not less than 50 per cent. of the gravel or stone for the concrete to be impervious.

In most specifications it is named that the Portland cement, leaving not more than a stated residue, shall

pass through a sieve having a certain number of wires per lineal or square inch. This residue varies from about 25 per cent. to 5 per cent. It is mentioned under the head of "Fineness and Weight," that the coarse particles left in their imperfectly ground state on the sieve after sifting are no better than sand, and some prefer sand to this residue. As the residue is generally used in the work, it follows that whatever proportion is specified of gravel and sand to Portland cement, practically the resultant proportion is increased, and therefore the concrete is weakened. For example, assume 10 to 1 as the proportion of gravel and sand to Portland cement and the residue as not to exceed 20 per cent.; provided the residue is used, which is almost invariably the custom, the proportion in the work of the concrete is not 10 to 1, but

10 to $(1 - .20) = .80$ of Portland cement,

or a $12\frac{1}{2}$ to 1 concrete. A considerable difference, amounting roundly to a decrease in the tensile strength of about 25 per cent., and in the compressive strength of about 35 per cent. Hence the importance of a small residue and extreme fineness in Portland cement, and attention being directed to the actual and not the specified proportion of the aggregates.

The required proportions of the ingredients in Portland cement concrete are principally governed by the quality and character of the materials, the nature of the specification, and the purpose to which the concrete is to be applied. In sheltered works and in situations where no marked fluctuations of pressure are likely to

occur the ratio of the aggregates to the cement may be increased, but in all cases the question of cost, the risk, the exposure, and the strain must be taken into consideration, and also the durability of the stones forming the gravel.

In certain works the sea face and the space from the foundations to low-water mark might be of strong concrete, and the hearting above low water, and between the faces of the work, of a weaker mixture. Whether it is better to have one proportion throughout, or the faces and base to about low-water line of stronger concrete, is open to question, and no general rule can be prescribed; nor is it of much value to compare the cost of concretes in different works unless the conditions are known and are practically similar, as it depends largely upon the material and facilities at command.

It may be important to have water-tight concrete; if so, it should be remembered that a small hydrostatic head will cause water to percolate through such a mixture as 12 or 10 to 1, and that until a 6 or 5 to 1 Portland cement concrete is used it will not resist a considerable head of water; but by attention in the proportioning of the aggregates, incorporation, mixing, and deposition, the porosity of weak concretes can be considerably lessened.

In important works nominally 12 to 1 is the limit now reached for sheltered places, and from 4 to 8 to 1 is the most general proportion for exposed and variably strained walls. It is not prudent, if the concrete will be subject to severe strain and wave-action on an

exposed coast, that the proportion of 6 of gravel or stone and sand to 1 of Portland cement should be exceeded. 9 to 1 has been found to be too weak a mixture for exposed sea work, but 6 to 1 succeeded. The proportion should not be more than 6 to 7 to 1 for sea work deposited *in situ* in comparatively sheltered situations, nor more than 8 to 10 to 1 for blockwork similarly placed. In depositing freshly mixed concrete *in situ* it may be necessary to use a stronger concrete in the stormy than in the calm season.

There is no doubt that it is better to have the hearting of a pier 8 to 1, and a thick face and bottom and top cap of 4 to 1, than all the mass of a 7 to 1 mixture, although the cost may be the same.

It should be remembered that it by no means follows that one concrete, although equally proportioned to another, is of equal strength, as will be patent from these notes, for the quality and nature of the ingredients may be different.

Such a ratio as 12 to 1 should only be used when all the materials are of the best kind and properly tested, proportioned, mixed, and carefully and leisurely deposited; and at present this ratio should not be exceeded, particularly remembering that with a 20 per cent. residue of the cement after sifting being allowed the concrete is only about a 15 to 1 mixture in the work. Twenty years ago 6 to 1 was considered the prudent limit; 6 of Thames ballast to 1 of Portland cement was the frequent London practice. Then the tendency was to err on the side of great strength; now, although Portland cement can be obtained of good and

uniform quality, and has been employed with the proportions between the aggregates and the Portland cement more than double the limit usually adopted about twenty years ago, a general acceptance and use of so great a ratio without careful and expert supervision is to be deprecated. In this country at that period Portland cement concrete was generally only used for foundations, backing, and secondary works. For such important structures as dock and sea walls, breakwaters, bridges, &c., and other works of the first order, it was more feared than trusted, except by the few who knew its intrinsic value.

It should not be forgotten, however, that no authentic practical test on a large or a small scale exists of the behaviour of a 12 to 1 Portland cement concrete after fifty years exposure and strain, although there is some reason to expect it will be satisfactory, and that it will withstand the assaults of time, the disintegrating effects of the atmosphere, and the vicissitudes of climate, provided it is not exposed to wave action, and the face is protected and maintained. Portland cement, however, being so cheap, it is not true economy to have little cement in the mixture and to starve the concrete.

For exceptional work, where the concrete will probably be exposed to uprising water, or if it has to be passed through a great depth of water it should be richer than for ordinary purposes.

With regard to the comparative value of Portland cement and lime concrete, in many cases there is no doubt that instead of blue lias lime concrete, Portland cement concrete with a much greater admixture of

sand and gravel could be used at the same or even less cost with much increased strength, expedition, and durability. On this question, vide "*Cement and Lime Mortars*," p. 96.

Some comparative experiments by Mr. Bernays at Chatham Dockyard showed that concrete made of 1 part of blue lias lime to 6 parts of river ballast was not so good or reliable as concrete made of 1 part of Portland cement to 12 parts of ballast, and that blue lias lime concrete did not always set well under water.

CHAPTER VII.

MIXING CONCRETE.

Hand and machine mixing—Proportioning—Quantity and temperature of water, fresh and salt water, damping the aggregates, &c.

WITH regard to concrete-mixing machines, the great point is to see that they thoroughly incorporate the ingredients, and that the materials are not placed in one part of the machine to be ejected at the other before they are completely mingled. However, hand mixing properly supervised by experienced men, according to instructions, and performed by those familiar with the work, is preferred by many to machine-mixed concrete, for the following reasons:—It is found that the mixers do the simple mixing admirably, and usually more evenly and thoroughly than if done by manual operation; but the conveyance of the concrete when mixed from the machine to the site of the works is not so readily effected, the difficulty, and the thing to be guarded against, being the separation of the aggregates, i. e. the gravel and sand, from the matrix or cement. In fact, the concrete which has been properly made in the mixer becomes, as it were, unmixed in its delivery to the place of deposition. When delivered from the machine to a platform it has to be put into barrows and deposited, and as the mixing machine

cannot be easily moved, and the concrete has two deliveries instead of one, which latter is the case when it is mixed on a platform on the spot, mixers are at a disadvantage, and the particles forming the concrete may become separated, and the concrete anything but a homogeneous mass, and in the work consist of horizontal layers or laminations, possessing different degrees of strength.

If very large quantities of concrete are required to be mixed in a short space of time, the employment of mixing and delivering machines is almost a necessity. On large and confined works they can be so arranged as to deliver the concrete without materially disturbing it after the operation of mixing has ceased. At Newhaven a portable continuous mixing machine, running on ordinary rails, designed by Messrs. Carey and Latham, was used. It could deliver 70 cubic yards of concrete per hour into the timber framing, and a lineal yard per day of the upper portion of the breakwater was thereby completed. The fixed continuous machine automatically measured, mixed, and delivered 100 tons of concrete in twenty minutes. At Newhaven Harbour works it was found that the labour on a 100 ton bag of concrete cost 1*l.* 15*s.* by this mixing machine, and 5*l.* 5*s.* by piecework hand-mixing. The cost of mixing the raw materials by hand was about 1*s.* 2½*d.* per cubic yard, but only 5½*d.* by the portable machine.

The thorough incorporation and mingling of the ingredients should be effected without any pulverisation of the particles.

Mixing machines constructed upon the principle of

a bladed screw-shaft revolving in a trough, with a slight fall towards the delivery end, to which the materials are moved as the blades revolve, are greatly to be preferred for Portland cement and lime concrete to the pan and roller system, which deteriorates the mixture, inasmuch as it grinds and pulverizes the aggregates, thereby reducing the sharpness, coarseness, and angularity of the gravel and sand. The system of mixing by means of a bladed screw-shaft in a trough is also much more expeditious than the pan and roller method of incorporating the materials, which should be generally abandoned for mixing Portland cement mortar.

One of the best mixing machines is made of an open trough of wrought iron, 6 to 10 feet in length and from 3 to 4 feet in width. The lower half is semi-circular, and the top half slightly splayed outwards. A shaft from 3 to 4 inches square passes through the centre of the trough. On the shaft are fixed wrought-iron blades, about 14 or 15 inches apart throughout, the first blade being fixed at about 7 inches from the end of the trough. The blades project in different directions alternately, and are arranged so as to screw the concrete forward as the shaft revolves. The trough has a slight fall towards the place of delivery. At one end is a wheel, round which belting can be used for communicating motion. The blades are made of a length so as nearly to touch the sides of the trough. This trough can be fixed anywhere on a couple of trestles. Its cost, as stated by Mr. B. B. Stoney, is about 35*l*.

The above mixer is intended for ground lime or

cement, and not for lump lime, for which latter the pan and roller system is useful to crush the lumps of lime. It is claimed that 8 to 10 cubic yards of concrete or mortar per hour can be made with this mixer, with 30 revolutions of the shaft per minute when driven by a 3 horse-power engine, and that it makes as much mortar as twelve ordinary pan mills.

The experiments of Mr. Grant showed that neat Portland cement is weakened by being mixed in a mortar mill. The cement weighed $110\frac{1}{2}$ lbs. per bushel, and was in one case mixed by hand, in the other by a mortar mill, 30 minutes. At the end of one month that which was ground in a mill had less than 75 per cent. of the strength of that which was mixed by hand. One hundred and ninety experiments were made to ascertain this. The maximum strength of that mixed by hand was attained at five months, and that ground in a mortar mill at one month, the greatest strength of the former being nearly double that of the latter. The strength of that which was mixed by hand was maintained, while that which was ground in a mortar mill declined from the maximum in each case to the end of the experiments. The result being considered due partly to the process of crystallization or setting having been interrupted by the continued agitation, and partly to the destruction by attrition of the angular form of the particles. Professor Hayter Lewis's experiments confirm this view, vide p. 30. On the other hand, it has been stated that this decrease in strength of mill-mixed cement mortar as compared with hand-mixed is due to the materials having been mixed in the mill for

an excessive time, thirty minutes. If six or seven minutes were tried it was believed the results would be reversed, but this is an expression of opinion, and one which has yet to be proved by experiment.

Mr. B. B. Stoney's method of mixing the dry materials of concrete or mortar before delivery to the machine was as follows:—On a large tray the ballast or sand was firstly laid. Supposing the sides of the tray to be 4 feet in height, and the proportions required to be 6 to 1, planks 8 inches in height are fixed upon the top of the 4 feet height, and cement is deposited for that depth. Men then shovel the material into the mixer, pushing their shovels along the tray, which is open at both ends; thus the cement sheds itself uniformly down the slope of the gravel, and becomes mixed with it to a certain degree before reaching the machine. No hand-mixing is done; the materials after being tossed over are thoroughly incorporated by the first three or four blades of the mixing machine previously described. They then pass under the water-rose fixed at about one-third of the length of the trough from the upper end, and to the delivery end; the mixture of gravel, cement, and water being perfected, and the mortar or concrete issues uniform in colour and homogeneous in quality.

When the proportions of the different ingredients are fixed, if the preceding tray and plank system is not adopted, boxes should be made of different sizes, corresponding with the proportions of the cement and the aggregates. The cement-box should be made to hold the quantity of cement contained in a bag or

barrel, and the boxes for the shingle, ballast, gravel, or sand, should bear the proportion desired in the mixture, as trouble is saved, the operation of mixing is simplified, and it is obvious it is a ready check.

Respecting the relative merits of the tray and the box system of proportioning the ingredients. Both have their advantages, and are effectual, if due care is exercised. Provided the boxes are duly filled and deposited, ready for mixing in their regular rotation, it is perhaps easier to apportion the material in its correct quantity in a box than over a surface such as a tray affords, but, if the tray is rightly covered, there is not the chance of unequal dry proportioning which there may be should a box of cement be omitted; hence, all depends upon the supervision. For feeding a machine mixer, probably the advantage rests with the tray and plank arrangement.

The dry materials should not be lowered through the water between panels or covering, but should always be first mixed with water on land; neither should a box be filled with the dry materials and the water be added to them in the box, as the concrete in both cases will then be full of cavities, as the gravel and sand will settle about 15 to 25 per cent. in volume on water being added, depending upon the size and character of the ingredients.

If there is little room for mixing on the site, skips on waggons can be delivered containing the dry materials, the skips being divided into partitions, and each division containing the required quantity of Portland cement, stone, gravel, or sand, which can then be

mixed in a dry and in a wet state on the site, and be immediately deposited.

Respecting mixing the materials by hand, they should be turned over twice or thrice in a dry state and three or four times in a wet state, thus thoroughly mingling the ingredients; and the required quantity of water should then be gently added from a spout with a fine rose-end attached, so as to prevent any cement being washed away, and to uniformly wet the whole mass. If it is decided to damp the gravel, sand, or stone, of course, the mixture cannot be turned over in a completely dry state, which does not often happen in this country. In England, or temperate climates, there may not be occasion to damp the aggregates before mixing with the matrix, but it should not be forgotten that they absorb moisture, and may rob the cement of its proper share, if an allowance is not made.

None of the aggregates forming the concrete should be allowed before deposition to touch bare ground, unless previously cleaned; but should be mixed on a plank bed, and the cement be taken from the store direct to the mixing platform, or mixer; and no Portland cement or concrete after being mixed should be softened or re-mixed, with an addition of water to enable it to be deposited in work, as setting operations are most seriously affected by such action.

With respect to the water required in mixing in the test-room, only the exact amount necessary for mixing need be used, and consistent results in testing can only be obtained by adopting identical proportions of cement and water; but in mixing on the site in order to pro-

vide against evaporation, filtration, absorption by brickwork or stonework that the concrete may bear upon, a small excess of water above that required in the test-room is generally used to facilitate the filling of trenches and vacuities, to prevent cracks in the concrete, and also to counteract the action of the sun and wind; particularly if the work is above the natural ground level. An excess of water, however, in concrete mixing is an error, for then the water affects too much the grains of the cement, which should be merely brought to a gelatinous state, separates the particles of cement and sand, delays the hardening and drying of the cement, and makes it more porous than it otherwise would be.

It is advisable to ascertain the quantity of water required to bring a given measure of cement to a proper consistency, and it is important to mix concrete or mortar, to the same stiffness to attain equal results. The want of homogeneity and uniformity in strength, and in the colour and appearance of a concrete wall, is due, in great measure, to the proportions not being identical, and to a difference in the amount of water used in mixing; but it is difficult to make a concrete wall without a face-coating of exactly uniform colour and appearance.

In hand-mixing, labourers frequently add an excess of water to facilitate operations, or the water is added in irregular quantities, and unless carefully supervised the ingredients may not be properly incorporated.

It is important to reduce the water to a minimum and not to vary the correct quantity required to make the

cement into a paste. New, freshly ground cement absorbs more water than that not so recently manufactured, and fine sifted cement more than the same when unsifted, and quick-setting cement more than slow—about 10 per cent. additional. When water for mixing is used in large quantities it increases the bulk, but decreases the cohesive power. The amount of water required to bring the cement to a paste may vary with the state of the weather; in a hot and dry atmosphere the necessary quantity of water may be as much as 10 per cent. more than if the weather should be damp and humid.

At the Portsmouth Dockyard extension works, Mr. Colson found that the best proportion of water to cement, both as regards convenience of mixing and results, to bring it to a paste or workable condition, was 1 of water to 3 of cement by measure, or 1 to $3\frac{1}{2}$ by weight. A slight variation of these proportions may be required, depending upon the age and fineness of the cement.

Mr. Grant has shown by experiments that neat Portland cement mixed with 25 per cent. of water by weight had 22 per cent. less tensile strength than that mixed with 19 per cent.; but the quantity of water required for proper mixing varies according to the cement, the extreme range being from 16 per cent. in the test-room to 28 per cent. on the work when mixed neat, and the usual quantity from 18 to $22\frac{1}{2}$ per cent. For a mixture of 1 of Portland cement to 1 of sand, about 15 to 16 per cent.; and for a mixture of 1 of Portland cement to 2 of sand about 12 to 14 per cent. by weight; and about 10

to 12 per cent. (12 per cent. is the Austrian standard rule), by weight of the cement and sand is the quantity of water for mixing test briquettes, proportions 1 of Portland cement to 3 of sand. Fine sand usually requires about 15 per cent. more water than coarse sand.

Mr. Carey, at the Newhaven Breakwater and Harbour works, found that 21 to 23 gallons of water per cubic yard of concrete, i.e. gravel, sand, and cement, gave the best results. This would be from $\frac{1}{7}$ th to $\frac{1}{8}$ th, or 14 to 12 per cent. of the volume of the concrete. The concrete consisted of 5 parts shingle, 2 parts of sand, and 1 of Portland cement.

Care should be taken that the concrete when finally deposited in the work has the same quantity of water as it required for the test briquettes, and that it is sufficiently wet to be impressed with the hand, but not softer, in order that no cement may be carried away. A simple approximate test of the proper quantity of water having been used in mixing is by punning the concrete ; if the correct quantity of water has been used, no water will be spurted up on its being punned, but simply a slight surface exudation will be noticed.

Almost all the most experienced authorities agree that salt water is as good as fresh for mixing purposes, in fact, if the concrete will be deposited in salt water, some prefer that the water used in mixing should be salt, and not fresh ; and careful tests have shown that Portland cement is even better when mixed with salt instead of fresh water under certain circumstances, but some experiments mentioned in p. 66, do not altogether agree with the general opinion.

It is well to remember that the tests as to the effect of mixing Portland cement with sea water have been made with ordinary sea water taken on the British coast, the solid constituents of which are said to be about $3\frac{1}{2}$ per cent. by weight in 100 parts, and that the salts, some nine in number, are various, and that common salt is only one of this number, and that the quantity of saline matter in the sea varies considerably, the density increasing with the amount of salt; the greater the evaporating power, the saltier the sea, and that the water of cold climates is not so rich in salts as the warm seas. It is possible the action of very dense, i.e., very salt sea water, may affect deleteriously the strength of Portland cement, and it may reasonably be thought that as the quantity of the salts increase, their effect upon the cement will be accentuated. The range of the amount of salts in solution in sea water may be taken, in ordinary sea water as $3\frac{1}{2}$ per cent. by weight, to about $24\frac{1}{2}$ per cent. by weight in the case of the Dead Sea, a cubic foot weighing respectively 64·05 lbs., and 71·175 lbs.

Cement mortar, or concrete used for general purposes, should be mixed with fresh water, which, of course, should be as clean as possible, and free from much lime or acids; but if the work is on the sea front, there is nothing to prohibit sea water being used for mixing. All experiments indicate that the quantity of water used in mixing cement is of great importance, and as a rule, less water is required when salt water is employed, usually about 5 to 12 per cent. less.

The tensile strength of cement is reduced if too

much water is employed, and the quantity should be as small as possible consistent with proper mixing as the strength is thereby increased; but, on the other hand, it has been stated by experimenters that the difference decreases considerably with age.

Air holes occur in cement mixed too stiffly, which should always be removed; and after the water has been added, the concrete, when thoroughly mixed, should be put into its permanent place, and not be allowed to stand for any length of time after it is ready for use, unless there be particular reasons to the contrary.

Mr. Faija deduced from 360 experiments, in which all the details of the tests were identical, and in testing a cement weighing 112 lbs. per bushel, and which left a residue of 25 per cent. on a No. 70 sieve, and in gauging which 17·24 per cent. of water, whether fresh or salt, was used; that the salts in sea water deleteriously affect cement mixed with sea water, and afterwards immersed in either sea, or fresh water; but act beneficially when the cement is only exposed to the action of the air, and that the same salts have a decidedly favourable effect when acting upon cement mixed with fresh water; and concluded, therefore, that for marine purposes the portions of the work which are above high water should be gauged with sea water, and those parts below high-water level should be mixed with fresh water.

The water used for mixing should have a temperature not less than about 50°, or more than about 80° Fahrenheit. Mr. W. Maclay made upwards of 7,000

experiments on Portland cement, vide the 'Transactions of the American Society of Civil Engineers,' vol. vi., page 311, and found among other results, that the effect of lowering the temperature appeared always to be a lessening of the activity of the cement, while raising the temperature increased the rapidity of the setting, and the effect of age was to lessen the influence of temperature. When the water was at a temperature of 70° to 80° , and the cement, when moulded, at 40° to 60° , the greatest tensile strength was obtained ; some 10 to 20 per cent. more than at a 10° lower temperature. The results showed that Portland cement should not be mixed, or moulded, at a low temperature, or be dried in a high one. All temperatures are on the Fahrenheit scale.

In hot climates especially, gravel, stone, sand, and all aggregates, should be damped before they are mixed with the cement. From 5 to 7 per cent. of water by weight of the dry aggregates is sometimes used, the quantity varying according to their porosity; but the materials should only be damp, and not add to the amount of water allowed for the cement; and yet be sufficient to prevent the cement being deprived of the moisture necessary for it to become indurated.

Portland cement concrete if properly mixed, and of good quality, and completely protected from frost during mixing and setting, for all practical purposes may be considered when properly set, as not materially affected by it. The prosecution of a work, especially one of repairs, may, however, be so urgent that it may be

absolutely necessary to make and deposit concrete when the temperature is below freezing point, viz. 32° Fahrenheit. Hot water is occasionally used for mixing under such circumstances, which is objectionable. In any case the water should not have at the time of mixing a temperature above 80° Fahrenheit. Salt is sometimes added to the water ; for notes on sea and salt water, vide pp. 64–65 : but both heating the water and the addition of salt to it are mere expedients, and should, if possible, never be adopted.

No concrete should be made when the thermometer registers much below 40° Fahrenheit, for water from the temperature of about 39° expands as it becomes colder, but, on the other hand, contracts in reducing the temperature to about 40° Fahrenheit ; and its expansive force, from the state of maximum condensation to the freezing point, is exceedingly great.

The memoranda on p. 138 may be found useful in proportioning the quantity of water for mixing, &c. Mr. P. J. Messent, on the Tyne, tried mixing concrete in a diving-bell, but found that it did not succeed. In the first experiments the materials were mixed and filled into the bags in a dry state, but on examining them, it was found that they had sometimes caked on the outside before the water reached the central portion.

According to Mr. Dyckerhoff's experiments in 1883, concrete is stronger if made by adding cement mortar to gravel, instead of mixing cement and gravel direct ; and the strength of concrete was found to be much

greater when mixed in the air and afterwards immersed than if it was moulded under water.

Some specifications require the cement and sand to be first mixed dry, and the gravel added afterwards, also in a dry state, in order to make the mortar more uniform ; and this method is to be recommended.

CHAPTER VIII.

DEPOSITING IN WORK.

In layers—Punning—Methods of deposition—Expansion and contraction, and precautions against their ill effects, &c.

PORTLAND cement concrete should be deposited when it is thoroughly mixed, and fresh, and be carefully trimmed and gently rammed if deposited in layers, which increases the strength by adding to its density. Great care should be taken to obtain uniformity, and equal rate of setting, in order that there may be no partially set and soft places, and others hard and thoroughly indurated, which will very probably cause cracks in the work, due to unequal settlement, expansion, and contraction. Unless the urgent exigencies of the work require otherwise, it is well if the layer of concrete deposited in one day does not exceed about 18 to 24 inches in depth, but not less than 18 inches; because the joint of each layer is temporarily somewhat weaker than the solid portion. In preference to an increase of the thickness of the layers, the area over which the concrete is to be deposited should be enlarged proportionally in order that the required daily quantity of concrete can be used, and the progress of the work not retarded.

It is sometimes specified that three days shall elapse

before a fresh layer is deposited, but as expedition is almost always necessary in public works, such a length of time cannot often be allowed. The advantages claimed for the system of depositing concrete in steps are that there is more homogeneity of construction, the chance of vertical fractures is avoided, and no great weight is suddenly placed upon the foundations, and, therefore, unequal settlement is improbable.

The top bed of each layer should be roughed, thoroughly brushed, cleaned, and well watered with cement grout, in order to bond to the next stratum, and the layers should be of uniform thickness to ensure equal settlement, and to prevent cracks.

The punning, or ramming, should be done directly the concrete is deposited, and should not be long continued, in order that the process of crystallization be not interfered with, which commences directly upon moisture being applied; and it is not advisable to pun large masses of concrete if deposited in bulk, as the outside surface may then be made denser than the interior, and the concrete become of unequal consistency, but if placed in layers, gentle punning is advantageous.

Concrete should not be tipped into the work, but be gently shovelled into position on the level, if possible, and should not be thrown or cast in from a considerable height, which will separate the particles, and make air holes, or bubbles, in the mass; and it should be carefully punned if placed in layers and be deposited directly from barrows, in order that the heavier ingredients may not sink to the bottom, and to ensure that the concrete will be homogeneous, and not in

layers of unequal strength. If a mixing-stage at the bottom of the foundations cannot be constructed, or the concrete be lowered in skips, and provided it is necessary that the mixture should be gently dropped into its place down a shoot, or inclined plane; in order to counteract the separation of the particles and prevent their forming separate lines in the work, the concrete should after deposition be at once turned over, or re-mixed, without any addition of water, and then be gently shovelled into its place, trimmed, and punned, if in layers.

When concrete is deposited against brickwork, or masonry, the surface should be watered, or washed with a cement grout in order that the concrete may not be deprived of the moisture necessary for its complete induration; and if different mixtures are used, unless there are cogent reasons to the contrary, the richer in cement, which necessarily has the greater adhesion and cohesion, should be placed against the work, of whatever kind, already set.

Freshly mixed, or plastic concrete, if deposited gently in the sea will stand in a mound at an angle of about 45° , or a slope of 1 to 1.

With respect to the expansion and contraction of cement and concrete, pp. 11-13, 22-23, and 61-69, indirectly relate to the question.

It is doubtful if an authenticated instance has been recorded of serious effects to cement or concrete, after it has set, being *solely* produced by the degree of heat, or cold, usually prevalent in temperate climates, provided cracks and fissures do not exist in the cement

or concrete, and that water cannot percolate into the mass, and that the necessary care has been taken in making and depositing the concrete and in the selection of the materials. Generally it may be considered that cement, after having set, is not injuriously affected by changes of temperature.

During the operation of setting, if possible, the temperature should not be below 40° Fahrenheit on the ground, or more than about 90° in the air, in order that there may not be any expansion, by cold below about 40°, of the water used in mixing, or a detrimental abstraction of moisture either by heat, the sun's rays, or drying winds.

In countries subject to great variations of temperature, if concrete is used in large masses, and is exposed to the sun, it has been found that it expands, contracts, and shows cracks, and therefore, if it can be done, the concrete *in situ* should be protected from the sun's rays until it has thoroughly set.

At Buenos Ayres, Mr. Higgin overcame this difficulty, by introducing at intervals strips of thin plate iron. They were withdrawn before the concrete was fully set, and the joint left was made up with cement mortar.

Another method, sometimes adopted to provide against cracks and fissures, especially in thin work, owing to variations of temperature during the operation of setting, is by the use of cross-panelling of lath boards $\frac{3}{8}$ inch in thickness at intervals of about 10 feet left in the work, but carefully covered.

It has also been found that if long concrete walls

are not constructed in greater lengths than about 40 feet, that they do not crack or fissure in ordinary weather, provided the concrete is good and the necessary precautions have been taken in depositing.

For practical purposes any natural expansion, or contraction, of the sand, gravel, or stone, may be disregarded; hence it is the cement and the mixing and setting operations that alone may be taken as creating any variations in the size of the mass causing cracks and fissures. It is, therefore, obvious that the greater the ratio of the quantity of sand, gravel or stone, to cement, the less the expansion or contraction, if both masses are mixed and deposited under the same conditions; and experiments have proved this to be the case, as they have also shown that the expansion of Portland cement of good quality is very little, and is so slight that it need hardly be considered in ordinary use; but all Portland cements contract when drying and expand upon being put into water. The degree of expansion is greater in freshly manufactured cement than that taken from a store, after having been air-slaked and deposited some considerable time; and cements with an excess of lime in them, or those lightly burnt, expand the most. On the other hand, cements with an excess of clay in them, usually contract rather than expand; the over-limed cement being the most dangerous.

Some failures of concrete structures by expansion have been proved by M. Lechartier to result from an excess of magnesia in the cement, owing to its affinity for water: a white exudation being the result of such

excess and cracking and flaking of the surface, vide p. 41. A linear expansion of as much as 4 per cent. has been noted in cement made from magnesian limestone.

Good Portland cement, of English manufacture, does not usually contain more than about 0.33 to 1.00 per cent. of magnesia, and good German Portland cement from about 1 to 3 per cent.

Mr. Harrison Hayter recommends that Portland cement should not be used if it contains more than 1 per cent. of magnesia, and considers that there should be no carbonate of lime in it.

Attention to the following details will lessen the deleterious effects of expansion and contraction:—

The quantity of magnesia in the Portland cement should not exceed about 1 per cent., and no carbonate of lime should be present in it when used.

The Portland cement should be ground very finely, vide pp. 4–10.

There must be no tendency in the cement to “fly” or “blow,” vide pp. 22–23.

The Portland cement must be thoroughly air-slaked, vide pp. 11–13.

The temperature of the water used in mixing should not be less than about 40° Fahrenheit, vide pp. 66–68.

The quantity of water used in mixing should be reduced to a minimum.

The temperature of the air, or the ground, in or upon which the concrete rests should not be less than 40°, nor that of the air more than about 90° Fahrenheit.

The composition, mixing and depositing of the concrete should be equal and regular.

The concrete, if possible, should be deposited in layers and not in large masses; and, if in layers, it should be gently punned and all air bubbles removed immediately on deposition.

If concrete must be deposited in large masses it should be subdivided by vertical divisions, or thin partitions, which should be afterwards filled in with strong concrete. In submerged work, from low water level to the top of the superstructure is the portion of the work most subject to cracks and fissures. Vertical cracks much more frequently appear than horizontal.

Variations of temperature during the operation of setting should be reduced as much as possible.

The sun's rays, drying winds and draughts, should be kept from the concrete until it has set.

No wall length should exceed about 40 feet, without it being temporarily unattached to the next length.

In hot and very variable climates, thin iron plates, or lath strips, can be introduced at intervals, the former temporarily, the latter permanently; but all openings must be carefully filled with strong Portland cement concrete.

CHAPTER IX.

TABLE OF STRENGTHS.

The approximate comparative tensile strength of different mixtures of Portland cement and sand—The approximate comparative tensile strength of different mixtures of lime concrete—The approximate proportion between the tensile and compressive strengths of different mixtures of Portland cement and lime concrete—The approximate comparative compressive strength of Portland cement and lime concretes.

REFERENCE to the following tables will be found convenient when deciding upon the proportions of concrete. They give the approximate relative strengths of different mixtures of cement, lime, and aggregates, and are deduced and calculated from some tests appearing in a paper, volume lxii., part iv., p. 165, of the 'Minutes of Proceedings of the Institution of Civil Engineers,' read by Mr. John Grant, M. Inst. C.E., whose experiments are undoubtedly the most reliable extant, as they are made under the conditions that exist in practice, and with the greatest care. They have been here especially constructed in an entirely distinct form, in order to ascertain the approximate comparative value of Portland cement and different limes when mixed in various proportions with aggregates.

With respect to lime concretes mixed in the pro-

portions named in the tables, it should be noted that, if kept wet, their tensile strength increased considerably, and in no case, the experiments proved, was it diminished; but with Portland cement concrete, however, the relative increase of tensile strength, when kept wet, was less than that of the lime concretes, although, as a rule, more when kept dry.

Mr. Grant stated, that "from their generally lower strength and slower action it is much more tedious to test limes than cement, and it would take some years to get a sufficient number of results to form the basis for a sound judgment."

The appearance of fracture, or giving way, of Portland cement concrete under compression experiments, usually commences with from 40 to 20 per cent. less weight than that required to crush a block; but in the case of so variable a material as concrete there is no fixed limit.

It will be noticed that the compressive strengths of some of the lime concretes vary very irregularly, and not according to the quantity of lime present in the mixture; some lime concretes increasing in compressive strength as the lime is lessened, whereas the tensile strengths generally decrease as the quantity of lime to sand becomes less; but with Portland cement concretes both the tensile and compressive strengths generally decrease in strength nearly regularly as the amount of cement becomes less, and quicker in proportion in compression than tension.

Tensile Strength.

Tests end of twelve months. Sand weighed 96 lbs. per bushel. Each number the average of five tests. Briquettes, Mr. J. Grant's, the Metropolitan Board of Works, London, form— $1\cdot5'' \times 1\cdot5'' = 2\cdot25$ square inches. Briquettes kept dry.

The number indicates the relative strength, neat Portland cement being taken as 100.

Portland Cement. 114 lbs. per Bushel.	Portland Cement. 120 lbs. per Bushel.	Proportions by Volume.
100	100	neat.
72	64·5	1 to 1
51	38	2 to 1
42	32·5	3 to 1
35	29	4 to 1
30·5	24	5 to 1
24	18	6 to 1
11	12·5	8 to 1
9·5	9·5	10 to 1
6·9	7·5	12 to 1
The tensile strength per square foot of this neat Portland cement = 30·26 tons.	The tensile strength per square foot of this neat Portland cement = 35·5 tons.	

Tensile Strength.

Briquettes, Mr. J. Grant's, Metropolitan Board of Works, London, form. Kept dry. Sand 96 lbs. per bushel.

Grey Lime.

The tensile strength of grey lime mortar per square foot, proportions, 1 of lime to 3 of sand, is approximately 3·23 tons.

Relative Strengths.	Proportions by Volume.
100	3 to 1
87·5	4 to 1
60	5 to 1
41·5	6 to 1

Selenitic Grey Lime.

The tensile strength of selenitic grey lime mortar per square foot, proportions, 1 of lime to 3 of sand, is approximately, 8·23 tons.

Relative Strengths.	Proportions by Volume.
100	3 to 1
51	4 to 1
42·5	5 to 1
31	6 to 1

Lias Lime.

The tensile strength of lias lime mortar per square foot, proportions, 1 of lime to 3 of sand, is approximately 2·6 to 3·09 tons.

Relative Strengths.	Proportions by Volume.
84 to 100	3 to 1
57 to 102	4 to 1
44·5 to 67·5	5 to 1
38 to 48	6 to 1

Selenitic Lias Lime.

The tensile strength of selenitic lias lime mortar per square foot, proportions, 1 of lime to 3 of sand, is approximately, 5 to 5·9 tons.

Relative Strengths.	Proportions by Volume.
100	3 to 1
64·5 to 68	4 to 1
36 to 48	5 to 1
31·5 to 57	6 to 1

Selenitic Lime.

The tensile strength of selenitic lime mortar per square foot, proportions, 1 of lime to 3 of sand, is approximately, 8 tons.

Relative Strengths.	Proportions by Volume.
100	3 to 1
64	4 to 1
59	5 to 1
47	6 to 1

Note.—The numbers here given of the tensile strengths of limes show the proportionate approximate relative strength of different mixtures of the *same* lime, and not the relative tensile strength of the different limes. 100 is taken in each case, for ease of comparison, as the constant for a 3 to 1 mixture, i.e. 3 of sand to 1 of lime. The sand and briquettes were the same in each case, and all the tests under like conditions.

Proportions between the Tensile and Compressive Strengths of different Mixtures of Lime and Cement Concretes.

6 to 1.	Proportionate Strengths.	
	Tension.	Compression.
Grey lime concrete	1	7·6
Selenitic grey lime concrete	1	7·2
Lias lime concrete	1	7·7 to 19·7
Selenitic lias lime concrete	1	5·1 to 20*
Selenitic lime concrete	1	7·1
PORTLAND CEMENT CONCRETE	1	13·6 to 13·9

* Selenitic Rugby lias.

The tensile strength of a 6 to 1 Portland cement concrete is, approximately, 6·34 to 7 tons per square foot.

8 to 1.	Proportionate Strengths.	
	Tension.	Compression.
PORTLAND CEMENT CONCRETE	1	20·5 to 22

The tensile strength of an 8 to 1 Portland cement concrete is, approximately, 3·4 to 4·5 tons per square foot.

10 to 1.	Proportionate Strengths.	
	Tension.	Compression.
PORTLAND CEMENT CONCRETE	1	15·7 to 18·5

The tensile strength of a 10 to 1 Portland cement concrete is, approximately, 2·9 to 3·3 tons per square foot.

12 to 1.	Proportionate Strengths.	
	Tension.	Compression.
PORTLAND CEMENT CONCRETE	1	11 to 18

The tensile strength of a 12 to 1 Portland cement concrete is, approximately, 2·1 to 2·9 tons per square foot.

$$\frac{\text{Pounds per square inch}}{15\cdot55} = \text{tons per square foot.}$$

Tons per square foot $\times 15\cdot55$ = pounds per square inch.

Compressive Strength.

All briquettes, Mr. J. Grant's, Metropolitan Board of Works form, the gently curved. Briquettes kept in a dry state. Each experiment is the average of ten 6-inch cubes. All proportions by volume, and all tests end of twelve months. Gravel and sand weighed 137 lbs. per bushel.

Taking the crushing strength of a 6 to 1 grey lime concrete as unity, the corresponding compressive strength is given of each kind of lime concrete named, and of Portland cement concrete mixed in the same proportions.

6 to 1.	Lowest.	Highest.
Grey lime concrete	1	1
Selenitic grey lime concrete	1·82	1·82
Lias lime concrete	1·12	2·26
Selenitic lias lime concrete	1·69	3·64*
Selenitic lime concrete	2·61	3·34

* Selenitic Rugby lias lime.

6 to 1.	114 lbs. per Bushel.	120 lbs. per Bushel.
PORTLAND CEMENT CONCRETE	9·88	8·47

The crushing strength of grey lime concrete 6 to 1 is, approximately, about 10·20 tons per square foot. The crushing strength of Portland cement concrete 6 to 1 is, approximately, about 87 to 101 tons per square foot.

Compressive Strength.

The proportional crushing strength of grey lime concrete 6 to 1 to 8 to 1, is as 1 is to 0·45.

8 to 1.	Lowest.	Highest.
Grey lime concrete	1	1
Selenitic grey lime concrete	1·66	1·66
Lias lime concrete	2·33	2·41
Selenitic lias lime concrete	4·27	7·44*
Selenitic lime concrete	3·32	4·74

* Selenitic Rugby lias lime.

8 to 1.	114 lbs. per Bushel.	120 lbs. per Bushel.
PORTLAND CEMENT CONCRETE	16·61	19·94

Taking the crushing strength of an 8 to 1 grey lime concrete as unity, the corresponding crushing strength of each kind of lime concrete named, and Portland cement concrete, mixed in the same proportion, is given in the preceding table.

The crushing strength of grey lime concrete, 8 to 1 is, approximately, about 4·6 tons per square foot.

The crushing strength of Portland cement concrete, 8 to 1 is, approximately, about 77 to 92 tons per square foot.

Compressive Strength.

The proportional crushing strength of grey lime concrete 8 to 1 to 10 to 1, is as 1 is to 1·13.

10 to 1.	Lowest.	Highest.
Grey lime concrete	1	1
Selenitic grey lime concrete	1.57	1.57
Lias lime concrete	1.64	2.21
Selenitic lias lime concrete	1.97	4.06*
Selenitic lime concrete	2.60	2.96

* Selenitic Rugby lias lime.

10 to 1.	114 lbs. per Bushel.	120 lbs. per Bushel.
PORTLAND CEMENT CONCRETE	10.3	10

Taking the crushing strength of grey lime concrete, 10 to 1 as unity, the corresponding crushing strength of each kind of lime concrete named, and Portland cement concrete mixed in the same proportion is given in the preceding table.

The crushing strength of grey lime concrete 10 to 1 is, approximately, about 5.2 tons per square foot. The crushing strength of Portland cement concrete, 10 to 1 is, approximately, about 53 tons per square foot.

Compressive Strength.

12 to 1.

The proportional crushing strength of Portland cement concrete, 10 to 1 to 12 to 1, is as 1 is to .69.

The crushing strength of Portland cement concrete, 12 to 1 is, approximately, about 37 tons per square foot.

CHAPTER X.

FACING CONCRETE.

Use of system—Necessary precautions—Joints.

MR. BERNAYS, at the Chatham Dockyard extension works, extensively used a system of facing concrete walls made of 12 parts of river Medway gravel to 1 of Portland cement. He faced the dock and retaining walls with great success with 9 to 10 inches in thickness of 4 to 1 concrete, consisting of 4 parts of broken slag or flint, 2 parts of sharp sand, and 1 part of Portland cement. This face concrete was so hard that it might be cut into for receiving bolts for fixing machinery.

There is no doubt that the plan of providing quay and other walls with a facing of stronger concrete is very effectual, as an 8 to 1 to 12 to 1 concrete hardly affords a sufficiently impervious, even, smooth, and equally hard face, without taking into consideration the appearance of the work. The same precautions should be observed before putting on the concrete facing as are referred to herein under the head of "Depositing in Work."

The face concrete should be well smoothed when wet and this should be done immediately on deposition, so as to obtain an equal appearance, and avoid patching it

afterwards, as in that case it will usually not dry exactly the same colour, and will show its edges, particularly against the other previously set concrete. In order to ensure a good joint between the work that has already set, and that about to be deposited, it is advisable to pick over, or serrate, the surface of the set concrete so as to ensure a rugged face to which the face concrete can adhere, and if ordinary precautions are taken, there is no reason to fear that the facing will separate from the main body of the wall, as is often the case with imperfectly faced brickwork, and ashlar faced rubble masonry. Consideration of the regularity and thoroughness of the bond over the entire face to be obtained with concrete shows, that the objections against face brickwork, or masonry, do not apply to a facing of concrete. It is acknowledged that the bond between the face and the backing of brickwork, or masonry, is not nearly so strong as in the body of the work; but in cement concrete facing with the usual precautions always taken in depositing a layer upon a layer of concrete, the junction of the face concrete with the main body cannot be weaker than the mass, but it is probably stronger; because the face concrete being richer in cement than that to which it is joined, and the cement being the material which alone binds the mass; it follows that the holding power of the face concrete is greater than the cohesion of the concrete in the main body of the work, and to which it is as perfectly joined as any layer in the mass.

No grouting with liquid concrete, or rendering of plaster, should be adopted for face work, but the face

concrete of a finer and stronger mixture should be filled in, worked, and pressed against the face mould, or plank, and all air should be expelled, or a smooth even surface will not be obtained. If such a surface is required the mould should have a planed timber face washed perfectly clean, and then a thin solution of soap, of the consistency of paint, should be applied over its surface before the face concrete is deposited; and the surface will be found to be smooth, beautifully even, and not mottled, if the mixture has been carefully and equally made.

It is preferable that the facework proceeds with the main work in order to have no joint with concrete that has previously set, which is necessarily temporarily weaker; but if the design of the work will not permit the face and main concrete to proceed *pari passu*, the richer, i.e., the concrete having the most cement in it should be joined to the poorer concrete, because the richer mixture has the greater adhesive strength, having more cement in it, and it should be noted that the cement alone holds the mass together.

Provided the necessary precautions are taken to have a clean and rough surface for the joint, freshly mixed or plastic, concrete may be deposited without fear on that which has previously set. If a stronger substance is joined to a weaker, it is obvious the stronger cannot give way before the weaker; and that, therefore, the joint of the fresh concrete with the indurated mass cannot be weaker than the main body of the weaker concrete.

When masses of concrete in walls have to be

frequently joined, a bond can be made by fixing as soon after deposition as possible, angular stones in the face, in a similar way to "toothing" in brickwork. Old short rails and pieces of iron are sometimes inserted for bonding purposes, and abutting recesses are left in work, to be afterwards filled with a strong concrete.

If it is necessary to use a grout to fill up joints, &c., it should consist of neat cement, and not of sand and cement, as owing to the diluted condition of the mixture, the sand becomes separated from the cement, the heavier from the lighter material. The grout should be as thick as possible in order to lessen the disintegrating effect of the excess of water.

CHAPTER XI.

CONCRETE ARCHES.

Not advisable to erect in certain cases—Methods of construction, &c.

IN arched concrete work, in order to prevent the chance of the face becoming brittle, the surface should be kept covered up, and in a damp state until it is thoroughly set, and the moulds and centreing should be allowed to remain as long as possible; and except in small arches which will not be subject to any severe strain, they should not be struck before 28 days has elapsed, instead of a week or ten days, usual with brickwork; although concrete arches of considerable span sometimes expand on setting sufficiently to lift themselves partially, or wholly from the centreing.

The great care necessary in the construction of concrete arches renders their employment undesirable for such purposes as railway underbridges, subject to a heavy and quickly rolling load, although admirably adapted for the abutments, wingwalls, and parapets, &c. of such bridges. The cost of arches in concrete under such circumstances will be found generally to equal that of a brickwork, or masonry arch; and there is great difficulty in obtaining men accustomed to such operations in the construction of ordinary railroads; and on railway works extending over several miles in

length, it is seldom that the inspection and supervision of any particular structure can be as thoroughly performed as on works concentrated upon one site, such as harbours, docks, and seawalls, &c., large viaducts and aqueducts; and without such constant supervision no concrete arch should be trusted. Also, the proper inspection of brickwork and masonry is more easily effected than concrete, and does not require the constant attention that is so absolutely necessary in concrete arch work.

On railways it is frequently imperative that the centreing should be struck within a few days of erection, which must not be done with concrete arches, especially when destined to bear severe and sudden loads.

In situations where the rolling load is heavy and the speed great, the soil of a yielding nature, and the bridges isolated, there is no saving in expense in the employment of concrete for arches; on the other hand, if the load is stable and invariable, and several arches have to be erected, it is economical and safe to employ concrete. For skew arches in railway work it is not advisable to adopt concrete. The strain upon the triangular portion of the arch which forms that part which is not square with both abutments being compound, and the strength of such triangular portion being dependent upon the cementing of the materials, or adhesive strength of the cement, which is much less than the tensile strength, which again is very much less than the compressive strength, the stability of a concrete skew arch may be injuriously and unequally

affected. The approximate ratio of the adhesive to the tensile strength, and the latter to the compressive strength are referred to on pp. 19-20, 77-85.

If neither bricks nor building stone be available, and it is necessary that the centre line of the arch be at an angle with the road or railway, the concrete skew arch can be constructed on the rib system, each rib being square with the abutments; but the ribs should be well and frequently strutted and firmly tied together by iron struts and ties, or they will not be stable. The struts and ties are especially required at the springing level, and should be continued at intervals along the arch not exceeding about 6 or 7 feet. The ties should bind each rib to the others. It is important to remember that if the arch is not firmly fixed at the springing, it will not be a simple arch, but an arched girder.

For the supporting arches of the parapet walls of breakwaters, the vaults of reservoirs, and arches generally that are square with the abutments, and not subject to a heavy and quick rolling load, concrete is well adapted. They should be semi-circular, by preference, and care should be taken that the curve of equilibrium will always be within the middle third of the ring, and that no lateral movement of the abutments, or piers, can take place; and as concrete in arches and beams breaks somewhat suddenly without giving much warning, it is obvious great caution must be exercised in constructing such important and thin work.

The arch should be kept damp until set, and the con-

crete be thoroughly mixed, mingled, pressed, and gently rammed between the moulds and centreing, and great care should be taken that the moulds do not yield during deposition of the concrete, and until it has set, and that the arch is thoroughly combined and equal in strength.

The following are some methods of constructing arches in concrete :—

1. The building the arch of its full thickness throughout from the springing level to the springing level, which is to be preferred if its thickness is not more than about 2 feet at the crown, and the arch is not of large span.

2. Its construction by portions of the full thickness.

3. The building of layers extending throughout from the springing level to the springing level, and the depositing layers upon those already set, until the required thickness is obtained. Applicable for segmental arches of considerable thickness.

4. The arch to have a key of brickwork, masonry or iron, and to be constructed according to systems 1, 2, or 3.

The deposition of the concrete commences at the springing level and proceeds on each side towards the crown.

The concrete in method 4 can be more easily rammed and punned, and as the arch is divided into two parts during construction, there is not so much chance of unequal strength of the concrete, or effects of expansion and contraction, but there must be a thorough connection between the brick, masonry, or iron, keystone and the concrete.

One objection to concrete arches for variable rolling loads is that the material being so imperfectly elastic, the arch may take a permanent set of too great moment, may crack, and finally break. Also, if the abutments yield or spread, the arch cannot change, or slightly alter its form as an arch can composed of voussoirs, whether brick or stone, or of a material having considerable elasticity, such as steel and iron.

The difference between the crushing and tensile strengths of steel, wrought or cast iron, and bricks, is not nearly so great as that of Portland cement concrete, which should be remembered in the erection of any structures liable to a variable strain, and demanding a certain degree of elasticity ; however, it is not intended to depreciate the value of Portland cement concrete for archwork, but only to state that it is not a material as well adapted for isolated archwork, which will be subject to speedy, variable, and heavy rolling loads, as steel or iron, brickwork or masonry, and that concrete archwork, subject to such strain, requires very great care in erection.

As concrete arches are usually made of greater thickness than if constructed of brickwork or masonry, an additional thrust from this cause is created to that which would result from the employment of brickwork which weighs about 16 to 20 per cent. less than Portland cement concrete : or stone, iron, or steel, and consequently an increased weight is brought upon the abutments or piers and the foundations.

The thickness of a segmental arch of concrete should always increase towards the haunches, according to the

usual formula, and the backing, especially of semi-circular arches, should be deposited without delay.

It is advisable to make concrete for archwork richer in cement, or with less sand, than that of the other parts of a bridge, and with regard to the composition of Portland cement concrete in archwork, bearing in mind that it is the proportion of sand to Portland cement that principally affects the strength, vide p. 79, of tensile strengths of Portland cement mixed with different proportions of sand, unless the whole mass of the arch must be impervious to water, it is here recommended that very little sand should be used in Portland cement concrete arches, or in beams to resist transverse strain, although the vacuities may be 10 per cent. or more of the mixture; and that the stone or rock concrete should be faced in the manner described under "Facing Concrete," in order to exclude water and air from the strain-bearing portion of the arch—vide pp. 48 and 130.

If rock concrete is used, it is well if it be richer in cement at the junction with any brickwork, masonry, or concrete previously set.

CHAPTER XII.

CEMENT AND LIME MORTARS.

Portland cement mortar—Superiority to lime mortar—Softening cement mortar—Mixtures of lime and cement mortar—Roman cement.

PORTLAND cement possesses quick indurating properties, not simply confined to the exterior skin, and will harden readily under water ; but rich limes require time, and are slow and gradual in the process of hardening, and become indurated on the outside some time before the inside is set, and are, therefore, unequal in strength.

As foundations are frequently subject to the action of dripping water, and as such action on lime mortar most particularly, is very deleterious until the mortar has thoroughly set, which takes a much longer time than Portland cement mortar ; it follows that Portland cement mortar is to be preferred to lime mortar on this ground alone, without enumerating other advantages ; but care must be taken that only sufficient cement mortar is mixed for immediate requirements, and on no account must it be re-worked, and it should be used directly it is mixed.

Portland cement mortar used in the proportions of 6 or 7 of sand to 1 of Portland cement, is somewhat harsh, stiff, and raw in working. It is necessary to give it a free consistency to enable it to be easily manipu-

lated, and to use a small proportion of lime for that purpose, which is to be preferred to loam or very fine sand ; but the quantity of lime used should only be sufficient to make the mortar plastic enough for free use. The deteriorating influence of a small mixture of loam is marked in the early stages of the process of induration, but it is believed to decrease considerably when the mortar is thoroughly hard, and after some months have elapsed. If loam is used, it should not be in the form of loamy sand, but the sand should always be clean and sharp, and the loam be added separately. A small mixture of pure clay has been used with cement mortars to mitigate their roughness, and is considered by some better than loam ; but, of course, all cement mortars are stronger if not so mixed or adulterated.

It has been proved, by the numerous experiments of Mr. Colson, at the Portsmouth Dockyard extension works, that a mixture of 4 or 6 parts of sand to 1 of Portland cement produces a mortar far superior to any that can be made with lime, and at slightly less expense ; and that, as a general result, the adhesive power of mortar, mixed in the proportions of 8 of sand to 1 of cement, with the addition of a small quantity of lime, or yellow loam, to render the mortar more plastic and tenacious, was superior to grey lime mortar mixed in the proportions of 2 of sand to 1 of lime.

Mr. Bernays, at the Chatham Dockyard works, abandoned ordinary building mortar, and used a mixture of 1 part of cement to 7 parts of coarse, clean, sharp sand, and 1 part of foundry sand, the latter containing about 10 per cent. of loam, or about $1\frac{1}{2}$ per

cent. in the mortar ready for use. The loam was added to produce the necessary softness, and for easy working of the mortar.

Messrs. Bazalgette and Grant, in comparing Portland cement mortar with blue lias mortar, added in bulk in the experiments the quantity of lime to make it the same price as a less quantity of Portland cement, with the result that the Portland cement mortar produced much stronger brickwork than by the use of the proportionally increased quantity of lime mortar.

Mr. Baldwin Latham has stated that sewers constructed twenty years have been found with the lime and cement completely washed out, owing to the ammonia, by chemical action, converting the lime into a readily soluble material. Portland cement is better than lime for resisting the chemical action of sewage; lime made from chalk the worst.

An internal ring of brickwork protects the backing of concrete in sewers.

Portland cement and lime concrete, if used for the foundations of machinery, should be protected from oil and grease, as they have a tendency to disintegrate and weaken concretes.

Lime concrete sets much more slowly than Portland cement concrete, which in twenty-four hours, is generally sufficiently hard to resist injury from water agitated by ordinary pumping operations. Portland cement concrete should always be used in weeping, or wet foundations. Blue lias lime concrete is often used for the foundations of dock walls and similar structures, but from a depth of about 5 feet below the floor of a dock

all concrete should be of Portland cement. No advantage is gained by using a mixture of lime and cement. Upwards of 500 experiments made by Mr. Grant proved this. In saving cement, it is better to replace the cement taken away by gravel or sand, in preference to an addition of lime.

Lias lime should always be ground to a fine powder, as the quality of the mortar is improved by fine-grinding, and the slacking should take some time before the other ingredients are added, in order that all the particles may be thoroughly combined with water.

If lime concrete has to be lowered through water, before commencing the work, experiments should be made to ascertain if it will then harden and properly set, because with inferior hydraulic lime, concrete which would set in a few days if simply deposited into a trench, may not set when it has been lowered through water.

At Seacombe Ferry works, on the Mersey, random soft sandstone was adopted, set in hydraulic lime mortar, the stones being large, containing 20 cubic feet each. It was found that with a mortar of 1 of Halkin hydraulic lime to 1·57 parts of sand, the mortar was not sufficiently rich, but when the proportions were 1 of lime to 1·25 of sand, it withstood the action of the tide in unfinished parts much more satisfactorily. Portland cement mortar is to be preferred in such situations. A thin Portland cement coating on lime concrete will temporarily protect it, if such protection should be quickly required; but care must be taken to obtain a thorough connection.

Concrete made of quicklime has a tendency to swell. In summer this increase has been found to be about one thirty-second, and in winter about one forty-eighth ; but no reliance can be placed upon its swelling as sometimes it does not increase in bulk. Quicklime, if used for concrete, reduces its adhesive powers, and makes it friable, therefore, it should not be employed. It dries sooner than slaked lime concrete, and if any particular form is required, quicklime cannot be used.

The bulk or volume of mortars when mixed and ready for use is about two-thirds of that of the ingredients before mixing ; but it will vary according to the nature and the proportions of the aggregates.

Mr. Grant's experiments have demonstrated that Roman cement is about two-thirds the price of Portland cement, but that its strength is only one-third ; therefore it is about double the cost of Portland cement, if measured by strength.

The "Coignet" artificial stone, or concrete, has been extensively used in France for about twenty-five years. It consists of a mixture of sand, powdered hydraulic lime, and a percentage of slow-setting cement. The lime and sand are moistened with a very small quantity of water, and after that operation is completed, they are ground to a stiff paste in a mill, and moulded to any desired form. The proportions most generally used are as follows :—500 parts of sand to 100 parts of lime, and 50 or 25 parts of cement. This material has been used with success in France for all kinds of work. Bridges, viaducts, and aqueducts of considerable span

and importance have been constructed with it. A reference to p. 99 shows that no advantage is gained by using a mixture of lime and cement. A cement concrete is therefore to be preferred to one of lime and cement.

CHAPTER XIII.

THE DEPOSITING IN SITÛ SYSTEM.

Introduction—Adaptability—Loss of cement—Importance of impervious face—Preparing foundations—Panelling and framing—Fixing piles in concrete mounds instead of driving them—Design of work—Kinipple's system of construction.

ONE of the cheapest and most expeditious systems of concrete construction, especially applicable to comparatively quiet waters, and for moderate depths, and on a firm foundation, natural or artificial, is the depositing it in a plastic or freshly mixed state *in situ*, between or against framing, as no expensive or special plant is necessary, and the cost of moving blocks from the sheds to the site and setting them by divers is saved.

Provided concrete is protected from currents or waves, or motion of water during deposition, in order that no cement may be washed away, it is an advantage that cement concrete should be covered by water when it is deposited, and no Portland cement sets better than that immersed almost directly after it is in place, as the process of induration proceeds without the loss of moisture which occurs in concrete setting in the air. In all plastic or freshly mixed concrete lowered through water, there is a not inconsiderable waste of cement by its being washed out, varying in amount from about

10 to 20 per cent., and an allowance should be made to counteract it; but this loss may be lessened by careful deposition, and to obviate the reduction in strength, sometimes lengths of breakwaters are so constructed from about low-water level that the work is carried up in lengths faster than the tide rises, no water being allowed to flow over the concrete. There is no doubt, however, that concrete that has to be lowered through water, unless completely protected from any wash, is not so strong as that which is set without being deposited through water when in a freshly mixed condition. Such loss of strength has been roundly estimated at from 60 to 70 per cent. If desired, quick setting cement can be used for work below low water, and slower setting for that above. An addition of a small quantity of quick-setting cement immediately before deposition assists the concrete to resist currents of water, or wave action.

Some systems of construction for submerged, or partly submerged, works are:—

1. The depositing *in sitû* freshly mixed, or plastic concrete.

2. By depositing concrete placed in a bag or sack.

3. (a) The small concrete block system, blocks that can be deposited with ordinary lifting tackle.

- (b) The large concrete block system, blocks requiring powerful lifting machinery to deposit them.

- (c) The concrete block system, when special lifting plant must be used, and a wall length is deposited *en bloc*, as at Dublin, where a 5,000 cubic feet-block, weighing 350 tons, was put into place at one opera-

tion; probably the largest block yet made in the modern use of concrete.

Note.—Although it may be cheaper to make large blocks than small ones, the expense of the machinery for moving and lowering them is an item which frequently neutralizes the lesser cost of constructing large blocks.

4. The construction of quay and harbour walls, piers and abutments of river bridges, in loose soil by means of concrete cylinders, by preference placed upon the cutting ring on land before deposition.

5. By the employment of thin hollow cylinders sufficiently buoyant to float when water-sealed, by towing them to the site, sinking them by gently letting in the water, and depositing concrete in the still water in the interior of the cylinder.

All concrete work exposed to the waves should be faced with an impervious mixture of Portland cement and sand, a strong, durable, and non-porous face being of the greatest importance; and in selecting the stone, or gravel, it should not be forgotten that stone if quickly disintegrated by the sea when unattached to Portland cement, will also weather and waste away when bedded in cement; and that, as soon as such action commences it is merely a question of time before the whole mass becomes disunited and unstable, for the stone will be separated from the cement.

No open joints, cracks, or fissures, should be allowed in any work exposed to the waves, more especially within the limits of its greatest action; as both water and air penetrate therein and become compressed by

the impinging force of the waves, and have great powers of propulsion which may seriously affect the work on the unexposed side; vide, p. 130. To lessen the chance of cracks or fissures, in long concrete walls, it is well if they are constructed in lengths not exceeding about 40 feet, but care must be taken to connect the set work with that newly deposited.

Unless there are cogent reasons to the contrary, such as the exposed position of the works, the depositing plastic or freshly mixed concrete *in situ*, or the bag system in combination therewith, may be used in preference to the other plans; the joints being good, and if proper precautions are taken, this method of construction is sufficiently strong and more economical, always provided the water is not so disturbed as to interfere with the process of setting.

From low-water level the depositing *in situ* system can generally be used in ordinarily exposed situations, if the timber framework is carefully designed, and well covered with jute cloth; and the bag system can be applied from the foundations to a few feet below the level of low water, except in light sandy soils, or bad bearing strata, when the weight must be more equally distributed over the whole area of the foundation courses, or the bags may sink into the ground, and the work settle unequally.

The surface of the ground upon which the concrete is to rest should not be inclined in one direction transversely, but should preferentially slightly dip from both faces inwards; and if level, it is desirable at each face to dredge or excavate the foundation for about a

foot to form a trench in order that the base may be below the general level to prevent any chance of sliding action; if this cannot be done, a toe of concrete should be deposited on each side. The longitudinal bed should be made level in steps, and the ground previously dredged, or cleared by divers of all *débris* and loose material.

The dredging for foundations if done by a bucket or grab, worked by a crane on a barge is economical, because the crane can be afterwards used for lowering the skips, bags or blocks of concrete.

In estuaries, it may be necessary to cover the foundations with jute canvas lining before depositing the concrete if the water is muddy or has much matter in suspension, to prevent the concrete being damaged.

Where there is a change in the nature of the soil, as clay with rock, or sand and shingle with rock, or sand and shingle with clay, at the point of junction of the different strata unequal settlement may be expected, and the ground for some distance on each side of the alteration in the character of the foundations should be artificially protected, to prevent scour of the waves and probable breach in the work; and it may be necessary to protect the whole area of the softer soil.

The necessary examination and preparation of the foundations having been effected, the erection of the staging and framing can be undertaken.

Should the ground be rock upon which it is proposed to erect a concrete structure deposited *in situ* between frames, the uprights, or masts, forming the pile supports to the staging can be, if desired, of iron, the ends

having the form of a sole plate, a hole being previously drilled in the rock to receive a 2-inch or 3-inch pin passing through the sole plate, and firmly fixed in the ground; or timber piles can be placed in a disc, and be fixed by divers in the rock as previously described—another method is named on p. 111.

The frames can also be constructed of posts having grooves, into which panels slide, being tied together with $\frac{3}{4}$ -inch or 1-inch tie-rods, which can be built in, if desired. In all cases and systems the framework should be made of pieces of such size that men can handle them, and the usual dimensions of iron and timber should, if possible, be employed.

In adopting the ordinary method of constructing concrete works by means of the depositing *in situ* system, it is necessary to have framework and planking, in order that the plastic concrete may be retained in the form required and the cement not be washed out.

Perhaps it is better to erect a couple of whole baulks at intervals of about 30 or 40 feet, the distance being that of the working lengths, and at distances of 6 or 7 feet intermediate single posts, than have all single posts, or all double posts at wider distances apart; the chief point to attain is to give equal support to the planking. As the framework is practically a cofferdam, but free from any great pressure from a head of water, the established principles of cofferdam construction should be followed, although there is no puddle, and the objection to through bolts, a most important one in cofferdams, does not apply, for they are a necessity in ordinary framework for depositing

concrete *in situ* on a large scale. The bolts can be drawn after the concrete is consolidated, and to enable this to be done, timber trunking should be placed over them before the concrete is deposited. At low-water mark, ordinary cofferdam half-baulk, or double plank outside walings, should be inserted about 10 feet apart, but closer within the limits of wave action. No inside walings should be adopted, as they make recesses in the wall unless left in the work, which is unadvisable.

The planking can be of the ordinary dimensions, 3 inches or 4 inches in thickness, or battens of $2\frac{1}{2}$ inches in thickness, but, unless the height of the work is very small, and there are numerous temporary shores which can be erected if the foundation is rock, or very cohesive, and the wave action merely nominal, or the piling or masts to support the planking at frequent intervals; $2\frac{1}{2}$ inches is the least thickness of the planking that should be used. Care should be taken that there are no apertures, knot holes, or open joints in the planking, or the water may spurt and wash out the cement and cause holes in the concrete.

About $\frac{3}{4}$ -inch in diameter tie-rods, which pass through the work from side upright pile to side upright pile, can be put in, about 6 feet apart in the height of the pile, with the usual nuts, washers and timber cleats to prevent the bolt ends from being damaged. A tie-rod should also be placed as near the bottom as possible, and there should be rods at more frequent intervals within the limits of wave action, i.e., from a few feet below the level of low water to the top of the framework. The piles can also be tied diagonally on the face

by bars or strips, which is a good plan. When the bolts are withdrawn from the trunking, the holes should be most carefully closed on each side with neat cement, or strong cement mortar, rather quick setting, and the hole should be filled throughout its length.

For work of very large dimensions, of course, the timber uprights and walings must be increased in strength and number, and sometimes the main piles are made more secure by a little concrete being deposited round them at the foundation level.

The planking beneath low water mark must be either fixed by divers, or made to slide down between two piles, which is not an easy operation unless the piles are vertical and regular, and it necessitates recesses being filled in when the main uprights are cut off, if the face must be even, or the piles being left in. The framework can be built up *pari passu* with the concrete, and the method of building the panelling will be governed by local conditions; the principal difficulties of exposed timber framework in the sea being to prevent its being washed down and lifted. Loading with old rails, or iron, is frequently adopted to remedy this tendency. The frames should be so arranged that, by inserting temporary cross planks, a length at any point can be made like a box, which protects the concrete from the wash of the tide and wave action. The timber casing should be lined with strong jute, or sail cloth, nailed to the planking to prevent the sea washing out the cement.

It is obvious that much ingenuity can be exercised in designing the framing, and there is almost no limit

to its form and general design. Movable shields of timber, or preferably of iron, because it will not float, can be used.

For quay or harbour walls, of course, the piles and framework can be of much less strength than for breakwaters or exposed sea works.

In exposed situations, as the staging piles by themselves will usually withstand storms, it may be advisable to make the planking removable so that it can be taken away on a storm approaching, and the piles be thereby saved from extra strain, which may cause them to be destroyed.

With regard to the working length of a structure it should not be greater than can be evenly raised, and its extent principally depends upon the rate of mixing of the concrete and its delivery and deposition on the site. 16 to 40 feet is a range of length frequently used.

It is well if the frames are not removed for about three weeks after the deposition of freshly mixed concrete *in situ*. There should always be a duplicate set of planks, as the removing and refixing of the frames takes a considerable time; the framing should, therefore, be designed, in order that it may be expeditiously removed and re-erected. If desirable, the panelling can extend in sections of the height of the wall instead of over the whole face.

The permanent work may be so designed that it can support the temporary framing without piles. The central portion of a pier being first deposited by the aid of skips, or from a barge; the panelling, to

enable the face on each side to be erected, can be made by means of bars or other connections attached to it, thus dispensing with the face piling. This system, however, may require a richer concrete for the hearting of a pier than would otherwise be necessary, and it may resolve itself into a question of saving in the cost of the panelling, facility of erection, expedition of the work, reduction of exposure and increased strength of the framing, as against the extra cost of the stronger concrete.

To obviate the necessity of driving piles for the panelling, the system of making a mound or toe of concrete for the pile to rest in has been used by Mr. Strype, at Wicklow Harbour, with success, the pile being placed therein before the concrete is set. The mounds can be about four or five feet in height. An application of this system, by which no panelling is required below low water level, is as follows:—Two trenches are dredged or excavated, one on each face of the pier; concrete is then lowered by means of skips, or self-discharging boxes, until a mound of concrete is formed on each side, reaching to low water level, piles being fixed in the mounds, which are deposited at intervals along the length of the proposed structure; the slope of the concrete is usually about 1 to 1, or an angle of 45° . The toes or shoes of concrete will become in a few days sufficiently hard to secure the piles.

The panelling for a short length can be securely fixed to a portion of the structure already finished, and be made to project sufficiently for a few feet of

the pier to be completed, and it can be removed when the concrete has set, and be used for the next division of the work. At Colombo Harbour works the pierhead was erected by depositing plastic concrete inside a circular wrought iron tank or cylinder of $\frac{1}{4}$ -inch plates, stiffened and braced by T and angle irons. It was floated out and sunk on the site and then filled with concrete.

In designing a pier, breakwater, or wall, the method of construction, the framework, and panelling required, and the protection that can be afforded against storms, should be considered simultaneously with the laws governing the proper form of the structure, which latter do not come within the scope of these notes; however, it may be stated that the heaviest materials should be placed within the limits of wave action, and projections should be avoided; and it should be borne in mind that waves will glide over a smooth surface without injuring it, but may loosen an irregular face; and care must be taken that waves striking against the panelling do not fall or become driven by the wind, so that they drop upon the top of the work between the panelling. The greatest disturbance may be expected about and above low water mark, therefore it is advisable to have the planking and panelling made more secure from a few feet below that level and above low water mark. Rubble stone mounds, which will be perfectly stable a few feet below low water level, may be disturbed by the first storm, if placed above that height of water. These points should be remembered in designing and pro-

tecting staging and panelling against the sea, which has been known to have a force in the highest waves in a storm of upwards of $3\frac{1}{2}$ tons per square foot, although the average force in summer and winter may not be above about one-tenth, or one-third, respectively of the storm power.

The latter part of a gale or storm, i.e. when the wind commences to moderate, is generally the most destructive to works, as the waves become more solid, and have greater impactive force than when they are broken, thinner, and lighter.

It is impossible to compare structures differently situated, whether as regards stability, adaptability, the method of construction, or the cost. The depth of the water is most important, as it chiefly governs the force of the waves; the fetch of the sea, and degree of general exposure, and the intensity and direction of the prevailing winds, and many other local circumstances, must be duly considered. It may be advisable to graduate the strength of a pier according to the degree of exposure, instead of making it of equal strength. Breakwaters formed of solid concrete throughout are obviously stronger than if made of face walls of large blocks, or deposited *in situ*, and the hearting of rubble set in cement, or weaker concrete.

The situation of a structure may be so exposed that no setting operations may be possible at certain seasons, which may mean six months of the year, if then any but the block system is adopted there may be nothing for the men to do until the setting season

returns, unless there is sheltered work to construct. In very exposed places, as a general rule, the block system is the best to adopt, as the concrete is set before it is lowered through the water, and the only chance of failure is reduced, in a correctly designed breakwater, to one of defective deposition.

In all exposed works situated upon sand or movable soil, it is necessary to have a platform of rubble random work, or an apron of concrete in bags in front of the pier, on each side, to prevent the waves undermining the structure, the width of the platform being dependent upon the degree of exposure. Flat bags of concrete, containing from ten to fifty tons of concrete, laid upon the top of the berm of a rubble mound, and over its slopes and toes, have been found to effectually protect it from the wash of the sea.

It is of the greatest importance to exclude the air from any structure exposed to the sea, as by wave action it may become compressed and blow out the work; and that the concrete on the face of the wall should not be porous, as the compressed air and the hydraulic pressure created by wave action, will quickly disintegrate it and cause the face to scale off. In exceptional cases it may be advisable to coat the pier with a facing of granite.

In comparatively sheltered places, piers have been constructed of two retaining walls, one on each face; the seaside having a parapet, the hearting being of broken rock and gravel deposited in layers between the walls, thoroughly punned and consolidated by the traffic over it in proceeding with the works. The

roadway covering should be very carefully made, and should not be less than about 2 feet in thickness. In order to prevent any percolation of water, in adopting this bi-wall system with a central hearting, at the foundation level it is well to extend the concrete across the whole section of the pier, in order to tie and strut the base of the walls together; and the thickness of this foundation course should be not less than 3 or 4 feet, depending upon the width of the structure; and the upper surface of this foundation course should be sloped on each side against the wall, and there should be a solid concrete coping at the top, extending the whole width of the pier, thus making the cross section box-shaped.

In sheltered places, and on the unexposed harbour side of a breakwater, arches can be turned from about low water level, the arches being semicircular, and their width not greater than about one-third of the cross section of the pier, and the intrados of the archwork being a few feet below high water level. To prevent small vessels becoming held by the arches, a floating boom can be attached to the face of the archwork.

In all cases, especially on a shingly coast, it is necessary that the faces of a pier be able to withstand the attrition of shifting shingle or sand, which will abrade its surface exposed to the sea; and the face concrete must, therefore, be richer in cement than the hearting.

It has been found that ships, rubbing against a wall of concrete do not injure it if the face is of strong concrete, but that the square, blunt, iron-edged

bows of barges gradually wear holes in it. It may, therefore, be necessary to place fenders in the work to protect it.

Mr. Kinipple, at Quebec Harbour, deposited crib-work filled with plastic concrete partially set, it being floated out, and sunk on bearing piles. He has also shown, on a large scale, that plastic concrete, deposited in separate masses, becomes sufficiently set to be able to resist the action of a current of water, so that the cement is not washed out, and that it unites with other pieces when submerged.

His patented monolithic system of forming breakwaters, seawalls, and similar structures, which has been successfully adopted, consists in forming jointless masses of concrete *in situ*, neither divers, staging overhead travellers, nor other particular plant being required. The concrete is mixed either in bulk or block, and allowed to partly set or harden out of water, so that when thrown overboard into the foundations, or work, it is sufficiently hard to prevent the cement separating from the sand and shingle while being lowered through the water, and is yet soft enough when deposited to fall together and form a compact structure equal in strength to the hardest rock. This system has been adopted when the concrete was deposited at the back of sheet piling in depths up to 38 feet, behind small dovetailed blocks of concrete, and for a groyne when sheltered by a movable wrought iron shield. If seawalls are required to be built with a straight or curved face, iron rods are fixed in the foundation, between which

planks slide, which keep the concrete in the desired position for a few days until it is set and becomes hard.

This system is an important modification of the depositing *in sitû* method of construction, and, therefore, particular reference is made to it; perhaps the only demurs that may be urged against it are, that the disturbance of the mass *after* the process of setting has proceeded for some time weakens the concrete, vide "Time Required for Setting," pp. 25, 26: that depositing an unset mass in such an unprotected way results in a loss of cement and disturbance of the lump, and that, if the concrete is not cast into place until nearly set it will not reunite. On the other hand, experiments by Mr. Kinipple, at Garvel Park Dock works, Greenock, with a $3\frac{1}{2}$ to 1 concrete showed that if 8 hours in the air only elapse between mixing and deposition, the strength is not affected, but it then diminishes, and at eighteen hours it is about one-half the original strength, and that if rammed into moulds it will form a monolithic mass. A mixture of $3\frac{1}{2}$ of sand and ballast to 1 of Portland cement was left three hours to set, and a 6 to 1 concrete five hours, before being deposited. The best results were obtained when the concrete was mixed with the minimum quantity of water and rammed into boxes immediately on mixing operations being completed, and deposited when in a state approaching the solidity of stiff clay.

CHAPTER XIV.

LOWERING THROUGH WATER PLASTIC OR FRESHLY-MIXED CONCRETE AND CONCRETE BLOCKS.

Necessary precautions—Some different systems, &c.

WATER must not be allowed to percolate through plastic or freshly mixed concrete, and it should be at the head level to prevent any local flow, and to ensure that the concrete is deposited in still water instead of in a current. If calm water is impracticable the concrete should be made richer than would otherwise be necessary, so as to provide for some of the cement being washed out and lost. Concrete of the usual proportions will generally be secure against the action of moderate seas, after it has been deposited for twenty-four hours; but a practical test should be made in each particular case.

In a river, by temporarily enclosing the site of the structure, so as to prevent the action of the current being felt within it, but not with the object of keeping out still water, concrete can be, and has been, deposited through great depths of water, such as 50 to 70 feet, with complete success.

In tide work, when the concrete is in place, it should be carefully protected by means of a covering, if feasible; and as in almost all tidal rivers there is a deposit

at each tide, it is necessary, in order to ensure a perfect joint, and sound work, that such deposit should be removed either by flushing, brushing or scraping, before any fresh concrete is added.

To prevent the cement being expelled from the concrete, thick canvas sail, or gunny bag jute cloth, or tarpaulin, is a simple and good protection; if that is not available, planking laid on the work affords a partial guard, but all covering material must be weighted.

Care should be taken that uprising, or falling water caused by tidal action, however calmly, does not wash out any cement, and that the concrete is thoroughly mixed, and that in lowering it in skips, bags, or other apparatus, it is not jerked and shaken about so as to cause the aggregates to sink to the bottom; as should such action be created there will be veins and layers of unequal consistency and strength.

The methods employed for lowering and depositing concrete are numerous; in these notes only the systems most generally adopted will be mentioned. Not one is universally, economically, or practically applicable. Some systems, such as lowering concrete from a hopper barge, are only fit for sheltered places, or for calm weather. Plastic or freshly mixed concrete can be filled into frames by means of skips lifted and lowered by a crane on an overhead traveller, if the staging is sufficiently strong, and thus be deposited in comparatively still water; or can be put in place by a projecting crane, or other simple lifting, lowering, and self-discharging apparatus; which should lower and

deposit the concrete gently and slowly, and in designing a crane for depositing skips, the jib should be sufficiently high that the parapet can be erected with it between frames, the top of the parapet may, perhaps, be as high as 20 feet above the level of the roadway of the pier.

In lowering or raising concrete blocks, the ordinary "lewis" system, although the most convenient, is seldom used, as it is found that the lewises frequently split the blocks at the holes owing to insufficient bearing area; but blocks are often lowered by outside claws, or simple chain attachment. Pear-shaped, or oblong holes are also formed in the concrete blocks by moulds during the operation of making the block, which are removed upon its having set. An iron bar is passed through the hole having a T or other unequally shaped end, and is turned until the end of the bar interlocks with the underside of the block; it being returned and disengaged upon the block being bedded.

Very heavy blocks have been deposited by floating shears on an iron barge worked by steam. Mr. B. B. Stoney, at Dublin Harbour works, lifted and lowered blocks by such means, weighing 350 tons, of the following dimensions, 27 feet in height, 21 feet 4 inches in width, and 12 feet in length, making the same length of quay. Such a system requires special and costly plant, and is only justifiable under the circumstances of such a particular case as at Dublin.

It has been found that when concrete is deposited in a freshly mixed state in self-acting boxes, it should be in a considerable quantity, and not less than about two

cubic yards, as the increased weight produces greater cohesiveness of the material, lessens the effect of the cement being washed out, and the finer particles of the cement being separated from the coarser, i.e., the chalky ingredients from the clayey, &c.

Concrete can be deposited by means of box shoots with valves, and skips are sometimes lowered to divers and are not opened, or released until their correct position is indicated. The bottom of large skips usually opens on hinges, the hook which holds them being released by a trigger. If the skip is very large, counterbalancing weights are attached to assist the closing of the doors. Self-acting skips have been used holding as much as 15 cubic yards of concrete. Another arrangement of skip is that in which it is suspended from a self-disengaging claw, so contrived that the contents of the skip cannot be discharged until the bottom is reached. The boxes, skips, or bags should not be lowered very quickly, in order to allow time for the air in the concrete to escape, and gentle deposition is important in order that the loss of cement on first contact with the water may be reduced to a minimum.

Concrete can also be deposited by means of jute gunny bags, or sacking, which open on reaching the work, and can be manipulated by ropes, pulleys, or other usual lowering and raising apparatus; the bag being withdrawn when opened; provided there is no current, or wave action to wash out the cement, or precautions must be taken, such as temporarily covering it, or not expelling the contents of the bag until they

are partially set, and able to resist a current of water; the time required for concrete to attain such a state can be ascertained by experiment, and it can then be filled into the bags a few minutes before such a condition is approached; but it disturbs the process of setting, and is, therefore not to be particularly recommended, see pp. 25, 26. Iron, or wooden skips, or boxes, are better than bags for depositing concrete.

In rough water and an exposed situation, where it is impossible to lower blocks of concrete by aid of a floating stage, instead of an overhead gantry, a "titan," or projecting jib, is frequently used, running on rails laid upon that part of the work which is finished. The "titan" should be taken to a sheltered position when the day's work is done, and should be constructed to run backwards or forwards; but if the blocks are of average size an ordinary steam travelling crane can be used.

It is sometimes necessary that the work should be executed very quickly. If such be the case, it can be expedited by erecting a staging, because the "titan" can only be used as the permanent work is finished, as it must travel over it. The relative advantages of the "titan" and fixed staging systems should be fully considered before deciding upon the method of deposition. If the cost and the time required for execution be found to be nearly identical, the land method of deposition is to be preferred to the floating system.

At Trieste, concrete was deposited through spouts, the bottom of the latter being fixed in a casing of the form of the pier made of planks attached to piles. The depth of the water was forty feet. The deposition of

the concrete through the spouts was continued until it reached the surface of the water.

In depositing concrete through spouts there is great risk that the aggregates will become separated from the cement. The chief object to be desired in lowering freshly mixed or plastic concrete through water is to prevent any disturbance of the mass, and to deposit it in the work in the same thoroughly incorporated condition it possessed when the operation of mixing was completed; therefore the simple spout system is not a good plan, but a modification of it could be made in the following manner:—A light iron or timber cylinder made in lengths, with easily fixed joints, reaching from the stage upon which the concrete is mixed to a distance of about two feet from the bottom, with claws for it to rest thereon, could be used, inside which can be an adaptation of the system of the endless bucket dredger, with movable flaps, the concrete being simply placed in the bucket or buckets at the top on the flaps being lifted, and the discharge taking place in the usual manner by tipping, thus combining the advantage of protection afforded by the spout system without materially disturbing the concrete after it has been mixed. The buckets should be as large as possible, and at wide intervals. The lower end of the cylinder and bucket dredger could be moved, raised or lowered by a chain attached to a crane. A diver, with whom communication should be made by a speaking-tube instead of life-lines, would guide the bottom of the apparatus, and see that it discharged the concrete, and the buckets could be fed direct from the mixing stage.

CHAPTER XV.

THE BLOCK SYSTEM.

Adaptability—Making the blocks—Bond—Joints of blocks—Importance of solid top course, &c.

THE concrete block system in an open sea and exposed coast is to be preferred to the depositing *in situ*, or bag-work methods of construction, as there is no uncertainty about the strength and general quality of the blocks, as they are seen before deposition; but the contents of bags may be disturbed and uneven in strength; and, with regard to concrete lowered through water, it may not be of equal consistency.

Blocks of concrete can be made to dimensions by pressing or ramming the materials into moulds, which can generally be removed from twenty-four to forty-eight hours after they are filled.

The blocks can also be made in moulds simply by placing rectangular sand-bags one upon another until the required dimensions are reached. The mould so constructed must be lined with sailcloth, which must extend sufficiently to fold over the top of the concrete when it is at the right height, and then be weighted down. The concrete having had time to set, the bags are removed, and the sailcloth taken away. It is obvious that the side of any block can be used for the

face mould for another block to which it will become attached; but, of course, timber moulds are to be preferred, and the blocks are better shaped and the joints superior.

When concrete has to be made in very large masses, an additional quantity of cement should be used to that for blocks of ordinary dimensions. Care should be taken that the blocks have had ample time to set before being deposited; if not, they will be damaged by a current of water or the wash of the sea; and as concrete blocks do not usually harden so well in dry air, when exposed to the rays of the sun, as in water, it is not advisable to deposit them before from fourteen to twenty-eight days after being made, the time varying with the size. In hot climates the blocks should be watered or kept in a damp state for a few days after being formed, so as to keep them moist for equal and proper setting. Blocks of about 15 to 20 cubic yards will generally set in a month or six weeks, but the upper blocks should be allowed to set for a longer time, say about two months, before being deposited, as they may have to bear heavy loads from cranes, a "titan" (which may weigh from 150 to 300 tons), or other machinery, directly they are put in place, and may crack. A settlement will generally be caused, but if the blocks are properly made, set and deposited, and the foundations secure, it will usually not exceed from three to six inches.

Mr. Grant's experiments showed that if the quantity of cement is less than 1 to 2 or 1 to 3 of the aggregates, which is usually the case, the blocks should be

kept some time out of water in a damp place, and be allowed to harden before being used, and that in making blocks of Portland cement concrete it is desirable to occupy no longer time than is necessary to effect a thorough admixture of the cement with the sand and gravel.

There is a limit to the economical size of the blocks, which, to a great extent, is regulated by the plant and the facilities at hand for handling, moving and depositing them on the site; and the blocks should not be made too large for cohesion of the material. For sea work it may be important to have blocks of very large size, but they are most difficult to deposit from a floating stage in an exposed situation; but blocks that have to be set by divers should be large, as the stability of the work will be increased, and a decrease in the number of the joints will be effected, and a saving in the cost of laying will result, notwithstanding any small increase of expense by the necessity for the employment of more powerful raising and lowering machinery. The height of the blocks can be regulated so that the rate of laying from about low-water level exceeds the progress of the advancing tide.

Blocks for sheltered and secondary work, such as quay walls, can be made of a size a man can handle and weight he can lift, and be placed on the face, and can be grooved and dovetailed by filling in the groove with quick-setting cement, a protection thus being afforded to concrete to be deposited *in situ* at the back of or between face walls so erected in the case of a breakwater or pier. The unbacked up

lengths must depend upon the size and weight of the blocks and degree of pressure to which they will be subjected; however, they should not exceed from about 10 to 15 feet in length, and from 2 to 4 feet in height, the work being constructed in compartments. The surface of the concrete should be protected after deposition. It may be advisable to coat the exposed faces of blocks with a half, or one inch coat of 1 to 1 Portland cement mortar.

If possible, the joints of all blockwork should be grouted with neat cement. Great attention should be given to the joints, and the blocks should have grooves made in them, to be filled *in situ* with strong concrete or cement grout, thus connecting the blocks, the only objection to such grooves and joggles being, that if one block settles, others are affected.

The deposition of blocks on a foundation is a matter requiring attention when considering the question of bond. By placing one block upon another of the same size, if the under block subsides, the superimposed block is alone moved; but, if a bond is adopted, the blocks will overlap, and any subsidence of the base will affect the whole structure in a greater or lesser degree.

If the foundation upon which the blocks are to rest is soft and yielding, it is better not to have a longitudinal bond, but simply to place the blocks one upon another, or laterally bond them only, if they cannot conveniently and economically be made to extend the whole transverse width of the work; and there should be no longitudinal bond, in order that if the settle-

ment is unequal it can be readily altered without affecting any other length of the work. It should also be borne in mind that it is impossible to as firmly bed a block upon two or more blocks as it can be done upon one. In blockwork it is important to have a solid course or cap at the top, extending across the whole width of a pier or breakwater, and of a thickness not less than four feet to bind the structure together, and if the hearting is of different or a weaker material to the side walls, it is of increased importance. Before the cap is attached the hearting should be consolidated.

All vacuities between the blocks should be immediately filled with cement grout, which can be temporarily protected from the wash of water either by bags, timber strips, or other covering.

Before concrete blocks are deposited, the ground should be cleared either by divers or by dredging, and the blocks under water must be laid by divers, unless random work is adopted; and, if so, a long time should be allowed for it to take a permanent set. The usual practice is to set them dry below low-water level, and in cement mortar above that level; but it may be advisable and necessary to join the blocks together by clamps, in order not only to strengthen the work, but to keep the blocks in place until the next course is deposited. Vertical grooves can be formed in the sides of each block, and when placed side by side concrete can be deposited in the hollow, thus dowelling the joints, and no unoccupied space should be left. In order to tie the blocks together,

they are sometimes studded with rough projecting stones, all vacuities being filled, after deposition, with concrete. As previously named, of course, there may be situations in which the plain joint is preferable, or none other required; but it depends upon the nature of the foundation, and the degree of violence of the waves to which the blocks will be subject during and after setting.

At Kurrachee, the inclination at which the blocks are placed is $47^{\circ} 45'$, determined by experiment with a model; it was just sufficient to bring the centre of gravity of each block above the face of the block against which it leans, so as to prevent any tendency of the blocks to tip forward during settlement. At Colombo breakwater the blocks are set at an angle with the horizon of 68° , or a slope of 1 in 3.

At Manora breakwater, the blocks are laid at an angle of 75° or 76° , an inclination of about three inches to one foot; an angle of 60° has also been proposed.

The more acute the angle at which the blocks are laid, the greater must be the length of the jib of the crane, or "titan." When the foundation is yielding and insecure, by having inclined courses, it seems to be generally considered that the blocks can subside without cracking or damage; but where the seas are heavy, and in an exposed situation, on similar soil, the recoil of the waves would probably scoop out the foundation if the vertical system of breakwater was adopted, unless the blocks are deposited upon a rubble mound at its base, extending to three or four times the width of the breakwater; then as the sea

erodes the natural foundation on each side the mound will fall into it outside the vertical pier built upon the central portion of the mound, and will form its slope of stability, which will not afterwards be disturbed.

In concrete blockwork, exposed to the action of the sea, it is important that the blocks bear upon each other, and that the superincumbent weight is not removed, which may be the case if they are loosened through the sinking or unequal settlement of the foundation. It is difficult, however, to thoroughly bed concrete blocks when under water, for mortar cannot be laid between them; and unless they are very carefully made to identical moulds and have perfect corners, and even, level, and equal surfaces on all sides which will be in contact, they will be irregularly supported, or only at their edges or ends.

Great care should be taken in all concrete block work, that there are no vacuities, or open joints, or fissures. If there is any unoccupied space it will be filled by the waves, and as the time between them may not be sufficient for the water to escape, when each successive wave strikes the work, a sudden violent hydraulic pressure will be created, which may push the blocks on the harbour side from their correct position. Even if the water has time to leak away, the air may become compressed by the action of the waves, which will affect the blocks on the harbour side only; therefore, the joints of breakwaters and all work exposed to the sea, within the

limits of wave action, should be very carefully closed, and if cracks, or fissures appear, or any joints become open, they should immediately be filled, to prevent any accumulation of water in them, or the air in them becoming suddenly compressed. Probably the best way to fill up cracks, or gaps in concrete walls exposed to water, is to place a covering of wood over the joint or fissure to prevent the cement from running out or being washed away, and to gently deposit therein quick-setting cement, or a stiff impervious cement grout.

A mere comparison of the weight or size of blocks is not necessarily a criterion as to their relative stability. By simply adding to the length and height of a block, the surface exposed to the sea is equally increased, but by a greater width transversely with the line of the pier the resistance to motion is augmented. The effective increase of stability through additional weight and size can, therefore, only be measured upon the horizontal line of cross section of the pier.

All unprotected corners of concrete blocks should have rounded edges, to prevent injury from wear and tear, or from blows, and to obviate a comparatively thin angular surface being presented to the action of the weather and the sea.

Blocks in the same structure are sometimes made of different proportions of cement, sand, and gravel, the strongest mixture being placed in the most exposed situations. It is advisable, by way of precaution, to place experimental blocks, made of different proportions

of materials, in an exposed position upon the site of the works, to see the effect the action of the waves has upon them; and also if the bag system is used, bags should be similarly tried. The hardness and general cohesion of a block can be approximately tested by a hammer or steel-pointed bar. If the stones only loosely adhere to the blocks, it is a sign that there is not sufficient cement in the concrete.

It is most important to make the blocks exactly the same size, and all the surfaces that come in contact should be even, level, and identical in shape, in order to ensure equal setting and bearing, and prevent splitting and scaling, more especially with blocks set dry, i.e. generally those below low water, as the solidity of the work depends upon their being properly and equally set one upon the other, and their having similar surfaces. When set in mortar small inequalities can be removed.

Quay-walls can be constructed of concrete hollow cylinders, if the soil is loose, and be sunk therein, and be filled with concrete, or with damp sand well rammed if the bottom is sealed from water. Rings of the wells can be notched and cemented together and be placed upon the cutting edge on land before deposition. The bottom ring should be richer in cement than the other rings.

Mr. D. Cunningham, at Dundee Harbour, employed hollow blocks, and found that large concrete hollow blocks can be so thinly constructed as to float by their own buoyancy. They can be towed to the site, sunk, and filled, the internal concrete being thus deposited in still water.

CHAPTER XVI.

THE BAG SYSTEM.

Adaptation—Filling the bags—Work of divers, &c.

THE system of depositing bags of plastic concrete has been used with success, and is particularly useful for levelling stable or rocky foundations, and for making a platform for preventing the scour from the recoil of the waves from a structure. Among the advantages claimed for it are that accurate levelling of the foundations is not required, as the bags fit themselves into the undulations of the ground, and lie close together, and a cheap and expeditious level foundation is, therefore, obtained, especially on rock, without the necessity of levelling the ground; but if the foundation is fine sand, or of a soft, yielding nature, the bag system for foundations may fail, and a method must be devised for equally distributing the weight over the whole area of the ground by fascine work, the rubble mound system, or by very large flat bags thoroughly interlocked, which must extend beyond the faces for a distance equal to, or double the width of the vertical portion of the pier. In all works it is advisable to extend the bags from 6 to 10 feet beyond the face of the structure to be built upon it, to prevent cracks, and a tendency of the bags to fall

away from the face of the wall ; and there is not a good bed for the superstructure unless the bag foundation projects considerably.

Economy is also claimed for this method of construction, because the expense of making to a particular form, and the transport of heavy blocks is obviated ; and the bags taking a bearing and spreading out to fit others, causes them to be more stable in their resistance to the waves than cubical, or prismatic blocks simply placed one upon another. They have been used for all the constantly submerged portions of a breakwater, but it is found that, from a few feet below the level of low water, care must be taken to protect the bags from being torn by the wash of the sea before the concrete has had time to harden, and the bags are sometimes of double thickness to afford greater protection ; but cement concrete, if exposed to the action of the tide only in bags of sailcloth or jute canvas, weighing about 20 ounces per yard, will set in a solid mass, and not much of the cement will be washed out.

In using bagwork in an exposed situation there is a loss of material and time, as the bags sometimes burst and become broken up and dispersed ; but there is no damage from this cause if blocks are used, and men can be employed in rough weather making the blocks when setting operations cannot be performed. On the other hand, if the work is situated in a sheltered position, the system of covering concrete with sailcloth, or placing it in bags, is not required unless currents exist, and the depositing *in situ* method of construction can be adopted.

Heavy seas will often tear up and remove the sail-cloth bagging from the concrete, but in ordinary weather it will protect the mass until it has set.

It is advisable, owing to the interstices between the bags, to keep the application of the bag system a few feet below low water level, so that they may not be exposed to the air which may get between the joints, become compressed, and blow out the work ; and similarly a severe hydraulic pressure may be created by wave action between the joints.

The bags of concrete are usually deposited by means of self-acting discharging boxes lowered from an ordinary barge, being so made that a bag of the same shape as the box or skip, is fitted into and temporarily fixed at the top ; when this operation is completed, it is filled with concrete, and the bag is sewn up, or a hopper barge is employed which drops her cargo of concrete in bag or bags over the prepared site. From 5 to 20 tons weight of concrete is generally put into a bag, or about 3 to 12 cubic yards ; but bags of 20 to 50 tons, deposited from a hopper barge, are frequently used ; and bags containing 100 tons and upwards have been employed.

It is found in practice that the bags fit and interlock into one another, notwithstanding the sacking ; although the adhesion of sack to sack does not of course nearly equal that of concrete to concrete, as the sacking prevents the chemical action of crystallisation between any masses of concrete in bags, and the joints are therefore defective, but the bags become firmly wedged. There is a limit beyond which the amount of concrete placed

in one bag cannot extend with ordinary sacking, as the concrete spreads and bursts the bags.

The bags should be guided to their position by means of divers, who should give information respecting the required dimensions of a bag to level the foundations, an allowance being made for subsidence and the flattening and spreading of the bag. Irregularities are generally corrected by beating the bags down with heavy rammers immediately on deposition, which should be done as quickly as possible, so as not to interfere with the process of setting; or the top of the bag is removed, and the material cut off to the required level, and covered up with sacking. The divers should be instructed to guide and gently ram the bags so that they are packed closely together; if this is done, no difficulty will be experienced in the joints of the bags, and the space between them will not generally exceed about three inches, but, as a rule, the larger the bags the greater the interstices.

The bags pack better when they are not very tightly filled, and the concrete not made too quick-setting, and there is some trouble to keep them square and level; and it is well, especially in large bags, to carefully fill the ends, as the concrete usually, during deposition, settles towards the centre, the bag slightly doubling up.

If necessary, neat cement grout can be poured gently through a pipe between the joints, which will help to join the bags. It is of great importance that the concrete in bagwork be thoroughly incorporated and mixed, in order that it may not strip or scale.

If concrete block work is to be placed upon concrete bags, the point of contact of the two systems should not be within the limits of wave action, and, therefore, the bags should only reach to a few feet below low water.

The four chapters, pp. 102-137, should be read collectively, as the subjects treated in them are intimately connected.

MEMORANDA.

	Approximate
FRESH WATER, weight per cubic foot in pounds	62·4
ORDINARY SEA WATER (containing about $3\frac{1}{2}$ per cent. of different salts), weight per cubic foot in pounds	64·05
THE DEAD SEA WATER (containing about $24\frac{1}{2}$ per cent. of different salts), weight per cubic foot in pounds	71·175

Weight of 1 bushel of fresh water	= 79·87 pounds.
" " ordinary sea water	= 81·98 ,,

FREEZING POINT, fresh water, 32° F.		
" "	salt water, 1 part salt, 4 parts water, 7° F.	
" "	brine, 1 part salt, 3 parts water, 4° F.	

1 gallon	=	·16 of a cubic foot.
8 gallons	=	1 bushel.
1 bushel	=	1·28 cubic foot = 2218·19 cubic inches.
1 cubic yard	=	21 net bushels.
1 cubic foot	=	·781 of a bushel.

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